National Library of Canada
Acquisitions and Bibliographic Services
395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale du Canada
Acquisitions et services bibliographiques
395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-28994-X

Canada

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Posterior- anterior Cephalometric Assessment of Adolescents with TMJ Internal Derangement** by Biljana Trpkova in partial fulfilment of the requirements for the degree of Master of Science in Experimental Medicine.

Dr. Paul W. Major

Dr. Stephen Bamforth

Dr. Narasimha Prasad

Dr. Keneth Glover

Date: April 17/98

DEDICATION

To my grandparents, Marija and Vane,

for teaching me that anything is possible

To my parents, Tina and Trajko,

for supporting me to accomplish my ambition

To my husband, Kiril,

for inspiring me

To my children, Bistra and Cvetan

for making my efforts meaningful

ABSTRACT

The objective of this study was to explore the relationship between temporomandibular joint internal derangement (TMJ ID) and vertical and transverse size as well as asymmetry of craniofacial structures in adolescent patients. The sample consisted of 137 preorthodontic adolescents (80 females and 57 males) with or without signs and symptoms of TMJ internal derangement. All patients received bilateral TMJ magnetic resonance imaging (MRI) and posterior-anterior (PA) cephalometric radiography. Multiple regression analyses were used to test the relation between objectively determined TMJ disc status and multiple cephalometric measurements of craniofacial dimensions and asymmetry for females and males separately.

The results in the female sample showed that increase in severity of TMJ ID on the right side was associated with shortening of the mandibular ramus and posterior facial height. Vertical asymmetry of the mandible was concomitant with this change. The association of TMJ ID and craniofacial measurements on the left side in females was weaker but consistent with the findings on the right side. In the male sample significant association was found between TMJ ID and vertical size of the mandible only on the left side. A small number of patients with TMJ ID in the male sample contributed to inconclusive findings for asymmetry. ANOVA analyses revealed that unless TMJ ID occurred bilaterally, there were no distinct differences in craniofacial dimensions between female patients.

TABLE OF CONTENTS

CHAPTER ONE

1.1 INTRODUCTION 2

1.2 STATEMENT OF THE PROBLEM 6

1.3 PURPOSE 7

1.4 RESEARCH QUESTIONS 8

1.5 HYPOTHESES 9

1.6 LITERATURE REVIEW 10

1.6.1 The mandibular condyle and its role in growth of the mandible

1.6.2. Epidemiology of TMJ Internal Derangement 17

1.6.3 Scientific evidence of disturbed mandibular growth due to TMJ pathology 23

1.6.4 The Posterior-anterior Cephalogram 27

REFERENCES 32

TABLE OF CONTENTS

CHAPTER TWO

2.1 INTRODUCTION 43

2.2 METHODS AND MATERIALS 46

2.2.1 Sample 46

2.2.2 Cephalometric analysis 47

2.2.3 MRI Analysis 47

2.2.4 Method Error 48

2.2.5 Statistical Methods 49

2.3 RESULTS 52

2.4 DISCUSSION 54

2.5 SUMMARY AND CONCLUSIONS 59

Table 2.1 60

Table 2.2 61

Table 2.3 62

Table 2.4 63

Table 2.5 64

Table 2.6 64

Table 2.7 65

Table 2.8 67

Table 2.9 68

Table 2.10 69

REFERENCES 70

FIGURE 2.1 74

FIGURE 2.2 75

FIGURE 2.3 76

FIGURE 2.4 77

FIGURE 2.5 78

TABLE OF CONTENTS

CHAPTER THREE

3.1 INTRODUCTION 80

3.2 MATERIALS AND METHODS 85

3.2.1 Sample 85

3.2.2 Cephalometric Analysis 86

3.2.3 MRI Analysis 87

3.2.4 Method Error 88

3.2.5 Statistical Methods 89

3.3 RESULTS 92

3.4 DISCUSSION 94

3.5 SUMMARY AND CONCLUSIONS 98

Table 3.1 99

Table 3.2 100

Table 3.3 101

Table 3.4 102

Table 3.5 103

Table 3.6 103

Table 3.7 104

Table 3.8 105

Table 3.9 106

REFERENCES 107

FIGURE 3.1 112

FIGURE 3.2 113

FIGURE 3.3 114

TABLE OF CONTENTS

CHAPTER FOUR

4.1 GENERAL DISCUSSION	116
4.2 RECOMMENDATIONS FOR FUTURE STUDIES	124
REFERENCES	126

LIST OF TABLES

Table 2.1	Cephalometric Landmarks and Reference lines	60
Table 2.2	Coefficients of Intra-observer Reliability of Lateral Cephalometric Measurements	61
Table 2.3	MRI Reproducibility Results. Coefficients of Reliability, Standard error's Maximum and Minimum Standard Deviation	62
Table 2.4	Cephalometric Measurements' Standard Error, as Estimated from Replicated Tracings	63
Table 2.5	Multiple Linear Regression Results for TMJ Score and Ipsilateral Facial Dimensions. Females	64
Table 2.6	Multiple Linear Regression Results for TMJ Score and Ipsilateral Facial Dimensions. Males	64
Table 2.7	Correlation Coefficients between Significant Variables in the Multiple Linear Regression Outcome and all other Cephalometric Distances and Ipsilateral TMJ ID Score	65
Table 2.8	Cluster Groups Formed by Combining TMJ disc Scores as Estimated with MRI	67
Table 2.9	Comparison of Cluster Groups I, II, III and IV for All Craniofacial Dimensions Derived From Bilateral and Vertical Measurements. One-way ANOVA Results for Females	68
Table 2.10	Comparison of Cluster Groups I, II, III and IV for All Craniofacial Dimensions Derived From Bilateral and Vertical Measurements. One-way ANOVA Results for Males	69
Table 3.1	Cephalometric Landmarks, Reference Planes and Asymmetry Measurements	99
Table 3.2	Measurement Error as Estimated from Replicated Tracings for Midline Cephalometric Variables	100
Table 3.3	Measurement Error of Bilateral Asymmetry Variables	101
Table 3.4	Range of Normal Asymmetry in Adolescents	102

Free of TMJ ID.

Table 3.5	Cluster Groups Formed by Combining TMJ ID Data: Right TMJ ID Score minus Left TMJ ID Score and Right TMJ ID Score plus Left TMJ ID Score	103
Table 3.6	Cluster Groups Based on TMJ ID Data, Regarding TMJ ID Side Dominance.	103
Table 3.7	ANOVA Comparisons of Amount of Asymmetry (Absolute Values of Asymmetry Measurements) for Cluster Groups I, II and III. Females	104
Table 3.8	ANOVA Comparisons of Means of Asymmetry for Craniofacial Measurements between Cluster Groups IV, V and VI. Females	105
Table 3.9	Multiple Linear Regression Analysis Results. Asymmetry Measurements Showing significance in Explaining the Variability of the Dependent Variables TMJ ID R, TMJ ID L, R-L and R+L. Females	106

LIST OF FIGURES

FIGURE 2.1	Cephalometric Landmarks and Reference Lines	74
FIGURE 2.2	Establishment of Plane for Quantitive MRI Assessment	75
FIGURE 2.3	Reference Points for Determining Disc Lenght and Disc Displacement	76
FIGURE 2.4	Cephalometric Variables Associated with TMJ ID. Females	77
FIGURE 2.5	Cephalometric Variables Associated with TMJ ID. Males	78
FIGURE 3.1	Cephalometric Landmarks, Reference Planes and Asymmetry Measurements	112
FIGURE 3.2	Establishment of Plane for Quantitive MRI Assessment	113
FIGURE 3.3	Reference Points for Determining Disc Lenght and Disc Displacement	114

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

Craniofacial growth is regulated by the same biologic factors that control the overall somatic growth. The end product results from the complex interaction of genetic and environmental factors whose most intricate relationships remain the focus of intense investigation. With the exception of the brain, the rest of the body grows intensely during the adolescent period. Increased growth rate of all the long bones and all the muscles in the body is the principal manifestation of puberty. [1,2] In concurrence with the adolescent growth spurt, significant facial changes take place, more consistently in girls and more variably in boys. Unfavourable factors such as malnutrition, disease, external pressure, interruption of muscular balance or damage to a growth site, etc. can exert a profound influence on the craniofacial complex during this critical stage of development.

Temporomandibular joint (TMJ) structural abnormalities are important etiologic factors that may lead to mandibular growth disturbances. The relationship between TMJ pathology and facial skeletal deformities was first reported by Boering [3] and Ricketts [4] independently in 1966. Certain craniofacial morphologies, such as asymmetry, Class II malocclusion, deep bite, and open bite are associated with signs and symptoms of TMJ dysfunction. [5] Variations in skeletal and dental patterns in both juvenile and adult patients have been correlated with structural and functional alterations of the TMJ [6,7] Although significant differences in sagittal [7] and vertical plane [6] were demonstrated in these studies, they have not been considered clinically

relevant.

The work of Dibbets [8,9] raised important questions regarding craniofacial morphology and the presence of TMJ disorders in a *growing patient*. It was demonstrated that juvenile patients with temporomandibular joint dysfunction (TMD) have distinct craniofacial patterns, mainly as a result of changes in the shape and position of the mandible. Shellhas et al.[10, 11] found a high prevalence of TMJ internal derangement in orthognathic surgery patients with mandibular retrusion and concluded that abnormal position of the articular disc is not only common but also causes abnormal facial growth and associated malocclusion. [10-12] This conclusion challenged the widely accepted doctrine that inadequate occlusal relationships give rise to TMJ related symptoms. Since the introduction of the TMJ syndrome by Costen [13] in 1934 the dental and medical community has considered occlusal factors as primary etiologic factors creating TMJ difficulties. Therefore, improvement of occlusal relationships was expected to prevent or improve an existing TMJ dysfunction. This belief has prompted elaborate debate whether certain orthodontic dental manipulations such as premolar extraction, incisor retraction and Class II elastics can produce TMD. Recent literature reviews by Sadowsky et al. [14] and McNamara et al. [15] have offered excellent evidence that "orthodontic treatment performed on children and adolescents is generally not a risk for development of TMD years later." Orthodontic treatment should not be planned to prevent or improve an existing TMJ dysfunction, although a TMJ symptom may be alleviated by correcting a disturbed occlusal scheme. [16]

The term "TMJ dysfunction" embraces a variety of subjective symptoms as well as objective findings. Lack of definition and precise criteria to identify and categorize these signs and symptoms complicates the study of TMJ disorders. Furthermore, the multifactorial etiology of this disorder also obscures the true incidence of TMD. TMJ internal derangement is but one subcategory of TMJ dysfunction and describes an abnormal position of the articular disc within the jaw joint. It is important to note that the myriad of scientific evidence put forth has not supported the existence of a unique "TMJ syndrome."[6-9]

The goal of orthodontic treatment is harmonious facial appearance. Since the question of *what* is wrong must precede the question of *how* it should be corrected, standards have been established to quantify the harmony and symmetry of the face that fulfils our basic concepts of beauty. These standards allow orthodontists to intervene with adequate treatment and anticipate a successful outcome. Scientific research is also concerned with the question "Why is it wrong?" Numerous growth-predictive theories have been designed to anticipate mandibular growth. In spite of intense research, deficiency of morphometric craniofacial analyses correlated with objectively determined TMJ internal derangement exists in the literature. Dibbets and Carlsson [16] proposed that further research should concentrate on determining facial characteristics in groups of patients based on TMD criteria, rather than searching for TMD signs and symptoms in groups based on certain dentofacial morphology. The possible role of TMJ internal derangement in unfavourable facial growth at the present time is

controversial. [16] Should such a role be established, disc displacement disorders may serve as predictors of mandibular and facial growth patterns.

1.2 STATEMENT OF THE PROBLEM

Orthodontists aspire to achieve stable and functional occlusion and at the same time to provide improved aesthetics and facial appearance for their patients. Contemporary knowledge of systemic and local factors that influence dentofacial growth allows orthodontists to adequately select and synchronize orthodontic treatment with growth and development.

It is well known that osseous TMJ pathology can compromise orthodontic and orthognathic treatment as a result of unfavourable mandibular growth. Soft tissue abnormalities of the TMJ include conditions referred to as internal derangement or disc displacement. Until the advent of soft tissue imaging techniques, TMJ internal derangement diagnosis relied on patients' symptoms, clinical assessment and radiographic changes. Magnetic resonance imaging (MRI) offers accurate diagnosis of TMJ soft tissue abnormalities while posing minimal side effects to the patient. The literature on TMJ dysfunction in juvenile patients has established evidence of altered craniofacial size in sagittal and vertical plane utilizing lateral cephalograms. Lateral cephalometry is limited because the right and left side measurements have to be averaged and transverse dimensions cannot be observed. It is not known yet whether disc displacement in the TMJ may exert undesired mandibular growth in vertical and transverse planes of space. It is also unknown whether unilateral or bilateral TMJ ID may contribute to the development of clinically significant craniofacial asymmetry.

1.3 PURPOSE

This study was undertaken to explore the relationship between temporomandibular joint internal derangement and vertical and transverse mandibular growth. This cross sectional investigation included adolescent individuals who were analysed cephalometrically for vertical and transverse craniofacial morphology and associated asymmetry. Patients were examined for TMJ soft tissue abnormalities using Magnetic Resonance Imaging. Multiple linear regression analyses were used to investigate the relationship between temporomandibular joint internal derangement and vertical and transverse measurements of craniofacial structures. Also, patients were classified into groups of unilateral and bilateral TMJ ID and craniofacial dimensions between different patient groups were compared.

Careful and comprehensive evaluation of the degree of TMJ ID should be undertaken at the beginning of orthodontic evaluation and screening if TMJ ID is related to unfavourable mandibular growth. The TMJ status information could then be used in anticipating mandibular growth and treatment planning and predicting a treatment outcome. The purpose of this study is to investigate whether TMJ ID is associated with altered vertical and transverse mandibular growth.

1.4 RESEARCH QUESTIONS

1. Is there a relationship between the vertical and transverse craniofacial dimensions and TMJ internal derangement of adolescent patients?

2. Do adolescents with TMJ internal derangement have greater vertical and transverse craniofacial asymmetry when compared to peers with normal TMJ-s?

1.5 HYPOTHESES

1. There is a correlation between TMJ internal derangement and craniomandibular size and shape in adolescent pre-orthodontic patients.

   A. Patients who have TMJ ID will have altered condylar growth on the ipsilateral side which will result in a decreased size of the mandible.
   B. An increase in severity of TMJ ID will be associated with a decrease in the size of the mandible.
   C. Patients with bilateral TMJ ID will have bilateral reduction of mandibular size in comparison to patients with unilateral TMJ ID.

2. Facial asymmetry will be associated with the degree of TMJ ID.

   A. Asymmetry will be more pronounced if the TMJ ID is a unilateral condition.
   B. In patients with bilateral TMJ ID, asymmetry should correlate with the difference between contralateral TMJ ID severity. If bilateral TMJ changes are of equal severity, asymmetry will not be greater than in patients without TMJ ID.

1.6 LITERATURE REVIEW

1.6.1 The mandibular condyle and its role in growth of the mandible

During the adolescent years, the broad and flat face of the child transforms through a series of changes and establishes balanced proportions with the cranium. Accelerated growth and development bring down and forward the middle face; concomitantly, the teeth erupt and the mandible follows these dynamic changes by enlarging its size and keeping pace with the main growth vector of the facial complex. The craniofacial proportions of the adult individual are established by the end of the adolescent growth spurt. [17]

Growth of the mandible depends on two synchronized processes, a slow remodelling of bone and a rapid proliferation of condylar cartilage followed by endochondral calcification. [16,17]

To understand the changes that occur during growth, the structure of the TMJ tissues and the sequence of normal developmental changes will briefly be summarized.

A. *Morphogenesis*

The mandible derives from the first branchial arch through an intramembranous process of bone formation, lateral to a temporary structure called Meckell's cartilage. In contrast, the cartilage that forms the mandibular condyle derives from mesenchymal cells *after* the membrane bone of the mandible and the TMJ component have been laid down through direct ossification, [18] thus the name, *secondary cartilage*. The first traces of condylar cartilage appear in the form of a carrot-shaped wedge in the ramus at approximately 12 weeks in utero. By 16 to 17 weeks IU, a fully

formed condyle is present, and the process of ossification is completed by the 20th week, save for a thin layer at the articular surface.

B. *Histomorphology*

Secondary cartilage develops when intramembranous bone is stimulated by local and intermittent biomechanical loading. The undifferentiated mesenchymal cells of the mandibular periosteal sheath possess an ability to produce either chondroblasts or osteoblasts. Under biomechanical loading, these progenitor cells adjust their activity to produce chondroblastic tissue. The degree of oxygenation of a tissue exerts control over the processes of osteogenesis or chondrogenesis. Hypoxia stimulates osteogenic activity while anoxia stimulates chondrogenic activity. [19] As a result of this proliferative activity the following four cell layers can be identified in sagittal sections of the condylar cartilage, moving from the outermost to the innermost layers:

1. Articular layer-- a fibrous tissue layer, covering the area of condylar articulation with the temporal bone. Bundles of thick type I collagen run essentially parallel to the surface, either anteroposteriorly or lateromedially. In young children, the cells of this layer are typical fibroblasts; during puberty, they gradually assume a chondrocyte-like appearance. [20]

2. Prechodroblastic layer-- a densely packed proliferative layer, a reservoir of mitotically active cells which render supplies for both the superior articular zone and the inferior chondroblastic zone. Two types of cells can be differentiated, based on their appearance: a polymorphic type in the upper two thirds of the layer, and a flattened type in the lower third layer. The collagen fibres in this layer are thin and form a loose meshwork.

3. Chondroblastic layer-- a hyaline cartilage-like layer, which resembles the growth plate of the long bone, although unlike the uniform and organized columnar

appearance of the growth plate it has a rather haphazard outlook. These cells gradually transform from being flat, through more ovoid to plump and hypertrophic that are embedded in large lacunae, especially in growing individuals.

4. Zone of endochondral calcification-- an area of intercellular matrix mineralization and chondroblastic transformation into osteoblasts. A continuously advancing calcification front gives the border between mineralized and unmineralized cartilage a scalloped appearance. [16]

C. *Stages of condylar growth and development*

1. Neonatal/juvenile period

Most of the major morphological changes associated with growth of the TMJ condyle are completed by the end of the first decade of life. The first few years of life are the period of the most dramatic changes within the tissues of the mandibular growth cartilage. The condyle of the neonate is capped with a thick, highly vascularized and mitotically active condylar cartilage. During the following three years, the thickness of the cartilage reduces markedly, mainly due to thinning of the hypertrophic layer of chondroblasts and assumes a sickle -shaped appearance. The thickness of the growth cartilage remains constant from infancy through adolescence. At this stage of development, the vascular canals, which are remnants of the embryonic blood supply system and which pierce the growth cartilage from the surface to the subjacent medullary cavities, gradually decrease in number. The last to remain are in the medial and posterior parts of the condyle, where growth is most active. They finally disappear by the end of the third year. [16]

Even the most prominent morphologic changes until the end of the first decade do not match the degree and intensity of the changes observed throughout the first three

years. One consistent finding is thickening of the articular layer and thinning of the cartilage layer. The underlying bony trabeculae condense and remain oriented supero-posteriorly, in accordance with the direction of condylar growth.

2. Juvenile/adolescent period

Between ten and thirteen years of age progressive growth of the TMJ condyle proceeds at a slower rate. A thick articular layer covers the abating growth cartilage, and continued mineralization of the deeper layers actively creates osseous tissue. A hallmark of a growing condyle, the hypertrophic cartilage layer is maintained to the age of 18 years. Between 10 and 12 years of age, a bone demarcation formed through merging trabeculae subjacent to the chondrocytic layer becomes evident. Its thickness increases gradually to reach a mature size of approximately 0.6 mm at 20 years of age. With the onset of a fully formed bony cap, the tissue immediately underneath the prechondroblastic cell layer becomes fibrocartilage, rich in collagen and extracellular matrix and scarce in cellular content. It is curious to note that the histologic appearance of the condylar growth cartilage during adolescence does not show evidence of an increase in thickness that might be correlated with the increased pubertal growth rate. [20]

3. The adult years

The TMJ tissues of an adult are fundamentally different from those of a growing individual. The fibrocartilage of an adult joint is an articular cartilage that serves primarily as protective tissue against articular loading. It retains a dormant potential for growth that can be evoked by certain local or systemic conditions. The process of cartilage replacement by bone is complete by the beginning of the fourth decade.

D. Mechanisms of growth

The role of the condyle during mandibular growth was considered of primary importance in the past. [17] Growth within the condyle was thought to displace the entire mandible and provide major contribution to mandibular formation. This classical concept considers the condyle to be a *growth centre*, with an autonomous, genetically predetermined potential for growth and enlargement, capable of generating an interstitial tissue- separating force which thrusts the mandible downward, away from the TMJ disc and glenoid fossa. However, both Moss in 1968 [21] and later Van Limborgh in 1970 [22] emphasized the importance of local functional and epigenetic factors as opposed to predominantly genetic control of growth. In support of this view, animal research experiments have failed to prove an independent growth of a transplanted condylar cartilage which is in contrast to the transplanted epiphyseal cartilage. [23] Thilander (1975), [24] in a histologic study of specimens from birth to the first few years of adulthood, supported the findings of Koski and Ronning, [23] Duterloo, [25] Durkin et al. [26] and concluded that unlike the long bones, the condylar cartilage is not a primary growth center, but that the growth of the temporomandibular condyle is of an adaptive nature. Mc Namara [27] demonstrated dramatic changes in the histologic appearance of the condylar cartilage following intermaxillary fixation in juvenile *Macaca Mulatta.* Namely, due to lack of functional loading, the thickness of the condylar cartilage was reduced to minimal. In contrast, both functional and intermaxillary mandibular protrusion resulted in increase of thickness of the cartilage. Thus, the condyle has a responsive rather than a pace-making role during the growth progress. The condyle's growth rate and growth potential should adapt to the environmental mechanical and other extrinsic stimuli and respond accordingly.

Luder (1996) [20] supported both views. He concluded that three basic mechanisms of condylar growth take place. *Appositional* growth is a proliferation of new

chondrocytes and their placement over the underlying cartilage surface. Equally important *is an interstitial* component of enlarging chondrocytes and increased cartilage matrix production. He stated:

The similarity of interstitial growth to the growth of the epiphyses does not exclude the possibility that condylar growth is adaptive, because local factors seem to affect both condylar chondrocyte enlargement and cartilage matrix production. Also, a systemic growth is not incompatible with adaptive growth, although results from experiments in culture suggest that at least part of the endocrine effects on condylar metabolism are direct, rather than mediated by some primary target tissue outside the TMJ.

The question of whether condylar growth is predominantly adaptive or intrinsic remains unanswered. However, it is certain that local epigenetic factors do influence condylar growth.

Another important issue to consider is the timing of mandibular growth. Description of growth and development may create an impression of continuos changes proceeding at a relatively steady rate. Brodie (1941, 1946), [28,29] and following him Sarnat (1968), [30] introduced the idea of a uniformly growing mandible. Hunter (1966) [31] correlated the growth of seven facial measurements with growth in height and reported that the anteroposterior length of the mandible (distance Articulare - Pogonion) exhibited a most consistent growth rate for both males and females. This finding was reproduced in other cross-sectional studies. [32] However, a cross-sectional sample can mask the variability of individual changes. Dibbets et al. (1987), [33] in a longitudinal study looked not only at the diagonal dimension of the mandible but at the separate growth rates of mandibular corpus and ramus. Several important conclusions emerged from this study. First was that the growth of the mandible is not a uniform, gradually progressing enlargement of the entire bone, since the growth

increments per individual patient did not show a steady increase but irregular curves with periods of acceleration and deceleration. Second, the summation of growth of ramus and corpus in proportion to the diagonal growth always remained a constant. This means that as the entire mandibular growth in length proceeds at a constant rate, the relative contribution to that growth alternates between corpus and ramus. This finding supported the assumption that external local factors influence mandibular growth. For instance, a local factor accelerates the growth of the corpus, while the growth of the ramus proceeds at a normal rate. Local adverse factors may also inhibit the growth of the ramus but the growth of the corpus may proceed and even compensate for the lack of growth of the ramus.

1.6.2 Epidemiology of TMJ Internal Derangement in adolescent population

Craniomandibular dysfunction, Temporomandibular Disorders (TMD), TMJ dysfunction and TMJ syndrome are some of the most frequent terms used in the literature to describe a condition characterized by pain in the preauricular area, the TMJ-s or in the muscles of mastication. In addition, presence of TM joint sounds, aggravation of pain during jaw movement and limited and/or deviant mouth opening are considered signs and symptoms of the disorder. Temporomandibular disorder (TMD) is the term recommended by the American Dental Association to encompass various clinical conditions such as pain in the masticatory muscles, internal derangement of the TMJ and degenerative joint disease (DJD). These three categories are not distinct from each other. A coexistence of myogenous pain and TMJ ID is common. DJD is most often associated with TMJ ID, although rarely it can persist as an autonomous entity. [34] Lack of criteria for differential diagnosis and standardized diagnostic tests have limited the attempts to trace the incidence, the prevalence, the natural history and the clinical course of TMJ ID.

Numerous epidemiologic studies and clinical trials on juvenile TMD have been published in the literature. [35-59] Subjective symptoms, as reported through a questionnaire or interview, and objective signs, as determined at clinical examination, have been the basis for most of the research in this area. Most frequently evaluated signs and symptoms include joint noises, muscle tenderness, TMJ pain to palpation, TMJ pain to function, limited jaw opening, irregularities on opening, wear facets on the occlusal surface of the teeth, and headaches. Helkimo in 1974 [54] devised an integrated anamnestic, clinical and an occlusal index to identify the presence and evaluate the severity of mandibular dysfunction. This tool has been used in many surveys that have examined TMD. [35,36,38,39,43-45, 47,48,52]

In asymptomatic adult populations the prevalence of TMD has been estimated to range between 30-50%. Epidemiologic surveys of TMJ dysfunction in children have found identical prevalence of clinical signs and symptoms, ranging from 30 to 52%. Mintz (1993) [60] reviewed 22 epidemiologic surveys on childhood and adolescent TMD and summarized that objective signs of TMD were found in 40.6%, while subjective signs had an average prevalence of 38.7%. TMJ clicking noises and masticatory muscles' tenderness were most frequent signs discovered during clinical examination. [52] Although the prevalence of TMJ problems in children may be as high as in adults, the symptoms are mild and transient in nature. The majority of these patients do not report any symptoms of pain and only a small percentage (6%) will require treatment. [61] To discern between potential patients with TMD and normal individuals, Wanman [47] recommended a thorough clinical exam for patients who complain of fatigue in the jaws, as in his study this complaint was most significantly related to objective TMD signs. Magnusson [45] suggested that decreased range of mandibular movement is a valid parameter of change in masticatory status. Objective signs of mandibular dysfunction gradually increase with age, but subjective symptoms between the ages of 10-15 remain unchanged (silent period). [43,45,48] Only one study [49] reported muscle tenderness as low as 1.7%; in a majority of other studies, the range was from 20% [50] up to 67%. [38] TMJ palpatory tenderness started at 5% [52] to reach 39%. [15] Headaches ranged between 11% [43] and 46% [35] with greater prevalence in older girls.

In general, more girls than boys in the older age groups report subjective symptoms, a trend that has been confirmed with objective findings [37,43,47,50,52,53] but some authors did not find any gender-related differences. [39,44,46,49] Only Dibbets [42,59] and Meng [41] included a radiographic evaluation of the TMJ structures. Deformed condyle was found in 1% to 16% of patients at the beginning of these studies and in 5% to 24% after a 10-year follow-up. Neither a particular subjective symptom nor an

objective sign could have been isolated as predictive of the future development of TMD, as all of them seemed to fluctuate with time in frequency and intensity. [43]

Internal derangement (ID) of the TMJ is a common *structural* intra-articular disorder, characterized by an abnormal relationship of the articular disc relative to the mandibular condyle, fossa and articular eminence. Disc displacement is synonymous with internal derangement and literally refers to any articular disc abnormality within the joint. Studies indicate that almost 80% of patients with TMD have a form of internal derangement. [61-64] Internal derangement can evolve from disc displacement with reduction to a more advanced condition, disc displacement without reduction, although the level of clinically detectable mandibular dysfunction is not necessarily related to the stage of intra-articular disorder. [65] The final stage can be degenerative joint disease, with morphologic changes of the TMJ components discovered on radiographic images.

Clinical determination of TMJ internal derangement is most often based on the presence of joint sounds during function. Sound evaluation involves checking for noises described as clicking, popping, crepitus and grating. Clicking sounds have been associated with disk displacement with and without reduction ; crepitation has been associated with degenerative arthritis. In addition, history of previous joint sounds associated with jaw movement as well as deviant or limited mouth opening indicate an internal derangement without reduction. Several problems originate from evaluation of joint sounds. First, the presence of joint sound can be due to reasons other than internal derangement, such as irregularities of the joint compartments, uncoordinated muscle function, sudden movement of ligaments, subluxation, fluid cavitation or lack of synovial fluid. [66] Second, if the disc does not reduce with the condyle during translation the joint is more likely to remain clinically silent [67,68] while range of movement may or may not be limited. [69] Chronic disk displacement with

reduction may not create joint sounds upon movement due to remodelling of the joint components. [70] Also, joints showing radiographic evidence of remodelling or DJD do not always produce joint sounds. [67,70,71] Sutton et al. [72] suggested that it is likely that all joints produce discrete joint sounds, but the sensitivity of the detecting tool limits our ability to detect them. The prevalence of TMJ sounds in asymptomatic children determined by palpation and unaided listening ranges from 2.7% to 26.6%. [66] In studies where a stethoscope was used prevalence rates range from 0% to 35.8%. [66] TMJ sounds detected during function may be episodic, fluctuating over time and spontaneously resolving. [36] Thus, the clinical significance of TMJ sounds remains unknown and based solely on a clinical exam there is a risk to either overestimate or underestimate the presence of internal derangement.

An increase of signs and symptoms of temporomandibular disorders with age has been reported repeatedly. Cross sectional studies have also reported increasing prevalence of TMJ sounds with increasing age. [40,49,50,52] However, in longitudinal studies the presence of TMJ sounds is described as intermittent and episodic, with the nature of the sound changing in character and the sound disappearing over time with or without treatment. [36,45,46,48] Keeling et al.[66] recorded TMJ sounds in 10% of the total sample of 3742 prepubertal children (aged 10 to 12 years). No gender differences were found. Gender differences in TMJ sound rates in children and adolescents have been found only for the older age groups, and more often in girls than boys. [36,43,50,52,53,66]

The concept of TMJ ID as a structural disorder, with anatomical intra-capsular change was challenged by Dolwick , 1996. [73] He reviewed the evidence for the significance of disc displacement as a major cause of pain, mandibular dysfunction, degenerative joint disease and growth disturbance. He concluded that there is insufficient evidence to establish strong support for the central role of disc displacement in TMD. His

argument was that the disorder is not necessarily due to a *structural*, macroscopic alteration but should be viewed as a *functional* disturbance with subsequent micropathology. Inflammation, effusion, tissue compression or stretching, tissue injury or breakdown are some of the possible co-existing factors in the pathophysiology of internal derangement. A sample of the synovial fluid would be required to determine such a change.

Accurate diagnosis of an internal derangement can be established with imaging techniques that reveal the soft tissue components of the TMJ and depict the positioning of the articular disc and the associated structures. Current imaging techniques of choice to determine a TMJ Internal Derangement are TMJ arthrography, CT Scans and MRI. Schiffman et al. [65] found a poor correlation between the level of mandibular dysfunction and the arthrographic presence or absence of TMJ internal derangement. While arthrography remains the technique of choice when TMJ disc perforation is suspected, its invasive nature and the patients' painful experience have placed MRI in favour when TMJ imaging is required. Magnetic Resonance Imaging allows excellent visualization of the components of the TMJ. It is a non invasive method which accurately depicts the soft tissue structures in various jaw joint positions and the chance of producing false negative results is reduced to minimal. The accuracy of MRI in diagnosing internal derangement has been reported to be from 73%[74] to 90% or more. [75] Imaging studies on asymptomatic subjects with clinically normal TMJ-s have revealed a disc displacement in 11.8% in orthodontic juvenile patients, [76] and 15% in adult patients. [77,78] Liebermann et al. [79] found a discrepancy of 54% between clinically diagnosed (59%) and MRI verified (5%) presence of internal derangement.

In summary TMJ ID are common clinical findings in adolescents. The patients often are unaware of the signs or ignore them as usually there is absence of pain or

impaired mandibular function. Age and gender differences are found in postpubertal children in contrast to prepubertal children suggesting that changes during adolescence may be linked to the appearance of TMJ dysfunction. This change is more significant in girls; hormonal factors as well as maturation of the occlusion have been implicated as contributing factors. [66] Clinical evaluation may not reveal approximately 50% of the patients with an abnormal condyle-disc relationship. [76] A structural abnormality of the soft tissues of the TMJ can be accurately diagnosed only with a soft tissue imaging. Because of the specificity of MRI in identifying patients with TMJ ID and because of its non invasive nature, it should be the technique of choice.

1.6.3 Scientific evidence of disturbed mandibular growth due to TMJ Pathology

The development of the occlusion requires that TMJ-s assume greater functional responsibilities. The condylar cartilage must become capable of growing under increased loading during mastication. As pointed out previously, for the cartilage to be stimulated to grow a certain amount of *physiological loading* is necessary. [15,80] Under regular conditions these events can proceed in a relatively coordinated fashion. As long as the external pressure from loading is in equilibrium with the internal pressure in the cartilage, the cellular layers can maintain their regular structure and function.[34] However, structurally, the cartilage is not well suited for growth under *adverse loading*. The prechondoblastic layer is unprotected as it is subjacent to the load-bearing articular layer. Once the physiological capabilities of these tissues have been exceeded, pathologic changes follow. [34] The TMJ tissues naturally possess an adaptive potential which can effectively resolve certain mild adverse events. However, any factor that may suppress the ability of the condylar cartilage to proliferate during the period of rapid facial growth could result in failure to achieve balanced and adequate mandibular size and shape. The initial insult may be mechanical , chemical or inflammatory. [34] Patients with juvenile rheumatoid arthritis (JRA) have a characteristic facial appearance as a result of micrognathia associated with inflammatory cartilage destruction.[16]

Both Boering [3] and Ricketts [4] recognized the presence of juvenile degenerative TMJ disease, and emphasized its importance in the development of disturbed mandibular growth. Boering followed the change of the skeletal structures in 400 patients that presented with osteoarthrosis of the TMJ-s over a 1-12- year period. His patient group was not juvenile, but in 34% of patients the symptoms of masticatory dysfunction had started prior to 20 years of age, while in two thirds of the sample the symptoms had begun prior to 30 years of age. He correlated clinical stages of TMD

(stage 1-clicking, stage 2-pain and limitation on opening, stage 3-no noise but crepitus) with radiographic changes. The condyles altered progressively; initially the condylar cortical plate disappeared from the antero-superior surface, and further, depending on the duration of the follow-up period, some demonstrated extensive loss of osseous structure with decrease in size and backward rotation. In 46% of the patients these changes were unilateral, and were positively correlated with subjective complaints, as well as shorter ramus. Vertical facial asymmetry as a result of ramus shortening was found in 13% of the sample. [81]

A characteristic growth pattern associated with presence of TMD in juvenile patients has been demonstrated.[8] TMD was diagnosed as presence of subjective or objective signs and symptoms (clicking, snapping and/or crepitation; pain in the jaw joints), as well as radiographic evidence of deformed condyles or Arthrosis Deformans Juvenilis (ADJ). [3] Craniofacial measurements included in the analyses were taken from lateral cephalograms. Assuming that TMJ disorder can occur during puberty, the author postulated that the dysfunction may be related to vertical shortening of the mandibular ramus due to remodelling, which in turn may result in impaired growth. Indeed, the children in the dysfunction group were more retrognathic, had a smaller overall length of the mandible, shorter posterior facial height, shorter ramus and shorter corpus, larger gonial angle and steeper mandibular plane. All these variables are associated with growth of the lower jaw and point to a smaller and abnormally positioned mandible.

Dibbets [8] assumed that subjective, objective and ADJ findings represented signs of one syndrome. However, the findings did not support this assumption. The deformed condyle was only weakly correlated with subjective and objective findings. Once the three dysfunction factors were segregated and looked at independently the emerging craniofacial patterns were markedly different. The group of children with objective

signs resembled children free of TMJ disorder. Point articulare in children with subjective symptoms was positioned more inferiorly, the mandibular corpus was shorter than normal, but the overall size of the mandible had not decreased substantially. The children with deformed condyles revealed greatest deviation from the control group, with the most striking feature being a short corpus, shorter posterior facial height, higher articulare and a pronounced antegonial notching. These findings point out that not all symptoms observed in children younger than 17 years of age can be attributed to TMJ dysfunction.

Adults with TMJ ID diagnosed with MRI showed a significant difference in both maxillary and mandibular body length from individuals with normal TMJ-s. [7] Decreased posterior facial height, a hyperdivergent skeletal pattern and increased horizontal discrepancy in an adult sample have also been reported .[82] All patients with TMJ ID in this study were diagnosed with arthrography, while the control group did not receive any imaging of the TMJ-s.

A high incidence of TMJ ID in patients presenting for orthognathic surgery with symmetrical or unilateral mandibular deficiency has been reported. [10-12,81,83] According to Schellhas et al. [10-12] TMJ ID can lead to deficient blood supply to the mandibular condyle, leading to avascular necrosis and osseous collapse or local osteoporosis. This concept has been widely debated, since a compromised blood supply to the condyle is unlikely to occur without causing substantial tissue necrosis, due to the collateral and well-developed vascular system in the condylar area. Dibbets and Carlsson [16] state that TMJ ID in absence of osteoarthrosis cannot impact growth. In their view, as long as the mesenchymal tissue covering of the condyle is intact, the growth potential of the condyle will be unaffected. A curious finding by the same author however contradicts this concept. Namely, in a longitudinal analysis of osseous changes of the mandibular condyle, it was demonstrated that juvenile

condyles with severe deformation possess a remarkable healing capacity. Absence of radiographic changes of the condylar tissues does not exclude previous destructive process in growing individuals. [42]

Nickerson [81] correlated radiographic with arthrographic changes within the TMJ-s of 134 patients (12 to 57-year-old). Ninety-eight percent of the joints that showed radiographic deformation of condylar morphology had an anteriorly displaced disc without reduction. This finding implicates advanced disc displacement without reduction as a possible precursor of osteoarthrotic condylar deformity. Initiating factors for the internal derangement could be systemic, such as substandard collagen structure, or local, such as adverse loading. Decreased synovial fluid production, biochemical alterations of synovial fluid, inflammatory mediators, metabolic changes in collagen, trauma, hypermobility or instability could also be involved. The course of disc displacement may lead to a failure to achieve full mandibular growth or to subtraction of already achieved growth in an older individual. [83] Although scientific evidence to date does not support the assumption that there is a compulsory natural progression of disc displacement with reduction to disc displacement without reduction and osteoarthrosis, a joint that is internally deranged is physically abnormal, and the effects of these changes upon facial growth are unknown.

The degree to which TMJ disorder can influence facial growth will depend on the time of onset, the duration of the condition and the severity of the dysfunction. The effects of unilateral TMJ ID may be different from those of bilateral TMJ ID. [3,8,16,83]

1.6.4 The Posterior-Anterior (PA) Cephalogram

The postero-anterior cephalogram is the only view that can reveal the transversal dimensions of the maxilla and the mandible as well as their relation to each other and to the rest of the craniofacial complex.[84] The width and angulation of the dental arches in relation to the cranium as well as the relative vertical dimensions of bilateral osseous and dental structures can be assessed.[85] Since the postero-anterior (PA) cephalogram accommodates the right and left structures at a relatively equal distance from the film and source, the technical difficulties due to disproportionate projection errors are minimized. Asymmetries in vertical and transverse proportions can be located and quantified by comparison of the sides.

Two potential types of errors are associated with PA cephalometrics, errors of projection and errors of identification. Projection errors are due to the arrangement of the actual apparatus as well as patient positioning. As a result of divergence of the x-ray beam, the imaged object is magnified and distorted, since points closer to the film are less magnified than points farther from the film. Only points that coincide with the axis (central beam) of the x-rays will be exempt from magnification.[85] Patient positioning is important to control head orientation. Although the cephalostat can minimize head rotation, it still has to be secured against soft tissues which can distort easily. Intraindividual anatomical asymmetries of the external auditory meati can also affect head position. The PA view is particularly sensitive to head rotation around the vertical and transverse axis. Rotation about the vertical axis will affect transverse relationships between the right and left side structures, while vertical relationships remain unchanged. The opposite follows when the head rotates around the transverse axis; vertical relationships will alter while transverse will remain unchanged. Five-degree rotation of the skull around these axes has been reported to result in an insignificant amount of error; rotation greater than five degrees is likely to be

recognized at the time of imaging [86]

Accurate identification of cephalometric landmarks depends on the density and sharpness of the radiographic image, the anatomic complexity and superimposition of hard and soft tissues, observers' experience when locating a particular landmark and the precise definition of landmarks' location. Landmark validity is the extent to which, in the absence of measurement error, the value obtained represents the anatomic structure of interest. Landmark reproducibility is the accuracy with which a landmark can be identified on repeated occasions.[87] Landmark identification error is generally larger when more than one observer is involved in the analysis despite a prior consensus on landmark definition and location. [85] Houston, 1983 [87] discussed methods of controlling errors in cephalometric analysis. Checking of measurements for "wild" values was suggested to be done either against previously published standards or against measurements of the study itself. Cephalometric tracings should be replicated and measured; error variance which is a measure of landmark identification error, should be a small proportion of the total variance.[87]

Each landmark demonstrates its own envelope of error, characterized by magnitude and distribution along the horizontal and vertical axis. [85,87,88] Therefore, the choice of landmarks used in a cephalometric analysis will be guided by the objective of the analysis. Landmarks with large horizontal identification error should be avoided for transversal measurements, while landmarks with large vertical error should not be used for measuring vertical dimensions. [85] El Mangoury et al. [88] studied the reproducibility of thirteen landmarks on the PA image. Dental landmarks were found less reliable as compared to skeletal landmarks. Major et al.[85] determined the reproducibility of 52 landmarks and concluded that many landmarks used in PA cephalometrics have an unacceptable magnitude of error.

Although numerous cephalometric PA analysis have been used, [89-103] there is no one analysis proven superior to others. [104] The objective of the investigation determines the choice of analysis. The first crucial step in PA analysis is the determination of reference lines. Structures to be used as reference system should be stable, should have a high degree of reproducibility and a high degree of symmetry. Three major concepts can be used to establish reference lines: [105]

1. Anatomic approach - a horizontal line connecting bilateral landmarks is drawn and a vertical line perpendicular to the horizontal reference and passing through an anatomical structure is constructed to represent the craniofacial axis. Landmarks that are in the proximity of the cranial base, such as the zygomatico-frontal sutures and crista galli have been used [89] as they were considered more symmetrical when compared to other landmarks that are farther from the cranial base. Lund [90], Stabrun [103], Alavi [102] have used the superiormost point of the orbital outlines to construct the horizontal reference line.

2. Bisection approach - crista galli and zygomatico-frontal sutures anatomically fulfil the criteria for symmetry and stability; however, both landmarks are difficult to identify and both have low reproducibility on the vertical axis. [85] A geometric approach could be used to overcome these problems. Multiple pairs of bilateral landmarks are located, joined with horizontal lines and then bisected. A vertical reference line is constructed passing through as many of the midpoints as possible. [93,94,97] When multiple pairs are chosen, if a midpoint is obviously off in relation to the other midpoints of the cranium and face, it can be excluded when drawing the axis. This approach relies on the accurate identification of multiple landmarks, which introduces greater risk for error. Also, minor to moderate asymmetry of a particular craniofacial region may not be detected since by constructing the best fit line the axis might minimize rather than reveal asymmetry.

3. Triangulation approach - following the identification of bilateral structures and the midline on the radiograph, triangles are constructed that divide the head into

various components. The surface areas of the right and left triangles are then compared for asymmetry. [93-95,98,101] This method can be used to study the relative asymmetry of the component areas of the craniofacial complex but the exact structure contributing to the asymmetry may not be identified.

The anterior cranial base completes its growth earlier then the rest of the face and offers stability required from a reference structure. From a region of relative stability, the evaluation of other growing areas of the face can be made. [17] For an asymmetry analysis, the reference system should also offer relatively high symmetry. The upper and middle face including the forehead and orbits as well as anterior cranial base are most symmetric regions. [92,95] Orbital landmarks have been used frequently in the construction of a horizontal reference line. The validity of the superior and lateral orbital contours as stable reference areas after eight years of age have been established.[102] The superiormost points of the orbits also have an acceptable identification error.[85]

Johnston, [104] proposed the intersection of the superior border of the greater wing of the sphenoid bone with the lateral orbital margin for construction of a horizontal reference line. The landmarks most appropriate for determining vertical reference line were the bisector of the line through the intersection of the inferior border of the sphenoid bone and the lateral orbital margin, and the midpoint of the nasal septum.

Grummons et al. [100] developed a PA analysis to provide information about specific locations and amounts of facial asymmetry. They used several horizontal reference lines located in different regions of the face to determine and measure vertical relationships. Transverse relationships were measured to a vertical reference line constructed between crista galli and anterior nasal spine.

In summary, when mandibular and maxillary size, position or asymmetry is in question, it seems appropriate to use a reference line system that will represent not only a stable and reproducible structure but also one that is separated from the areas of interest. [104] In this way, the observed values will likely be more representative of the objective mandibular and maxillary parameters. Separation of the reference system from the lower facial skeleton is also required to insure its stability from the effects of dentoskeletal changes due to orthodontic and orthognathic treatment. It would be preferable to avoid the use of maxillary or mandibular midline landmarks in the construction of vertical reference line.

References

1. Tanner JM. Growth at adolescence. 2nd edition. Oxford, Blackwell, 1962
2. Marshall WA, Tanner JM: Puberty . In Falkner F, Tanner JM, editors: Human Growth , vol. 2, ed 2, New York 1986, Plenum Publishing.
3. Boering G. Arthrosis deformans van het kaakgewricht. Stafley en Tholen, Leiden, 1966.
4. Ricketts RM. Clinical implications of the temporomandibular joint. Am J Ortho 1966 ;52 (6):416-39.
5. Moyers RE. The development of occlusion and temporomandibular joint disorders. In: Carlsson DS, McNamara JA, Ribbens KA, eds. Developmental Aspects of Temporomandibular Joint Disorders, Monograph 16, Craniofacial Growth Series. Center of Human Growth and Development, The University of Michigan, 1985:53-70.
6. Stringert HG, Worms FW. Variations in skeletal and dental patterns in patients with structural and functional alterations of the temporomandibular joint: A preliminary report. Am J Ortho 89:285-297,1986.
7. Brand JW, Nielson KJ, Tallents RH, Nanda RS, Currier GF, Owen WL. Lateral cephalometric analysis of skeletal patterns in patients with and without internal derangement of the temporomandibular joint. Am J Orthod Dentofac Orthop 1995;107:121-8.
8. Dibbets, JMH. Juvenile TMJ Joint Dysfunction and Craniofacial Growth: A statistical Analysis. Stafley and Tholen, Leiden, 1977.
9. Dibbets, JMH: Van der Weele LT, Uildriks AKJ. Symptoms of TMJ dysfunction: Indicators of growth patterns? The J of Pedodontics 1985;9:265-84.
10. Shellhas KP, Piper MA, Omlie MR. Facial Skeleton Remodeling Due to Temporomandibular joint Degeneration: An Imaging Study of 100 Patients. AJNR 11:541-551. May/ June 1990; AJR 155: August 1990.

11. Shellhas KP, Piper MA, Bessette RW, Wylkes CH. Mandibular Retrusion, Temporomandibular Joint Derangement, and Orthognathic surgery planning. Plastic and Reconstr Surg 90(2):218-229; 1990.
12. Shellhas KP, Pollei SR, Wilkes CH. Pediatric internal derangements of the temporomandibular joint: Effect on facial development. Am J Orthod Dentofac Orthop 1992;101:79-83.
13. Costen JB. A syndrome of ear and sinus symptoms dependent upon disturbed function of the temporomandibular joint. Ann Otol Rhinol Laryngol 1934;43:1-15.
14. Sadowsky C. The risk of orthodontic treatment for producing temporomandibular disorders: A literature overview. Am J Orthod Dentofac Orthop 1992;101:79-83.
15. McNamara JA, Seligman DA, Okeson JP. The relationship of occlusal factors and orthodontic treatment to temporomandibular disorders. J Facial Pain 1995;9:73-89.
16. Dibbets JMH, Carlson DS. Implications of Temporomandibular Disorders for Facial Growth and Orthodontic Treatment. Semin Orthod 1995;1:258-272.
17. Ranley DM. A Synopsis of Craniofacial Growth. Connecticut: Appleton & Lange, 1988.
18. Van der Linden EJ, Burdi AR, De Jongh HJ. Critical periods in the prenatal morphogenesis of the human lateral pterygoid muscle, the mandibular condyle, the articular disc, and medial articular capsule. Am J Orthod Dentofac Orthoped .1987;91:22-28
19. Hall BK. Tissue interactions and chondrogenesis. In: Cartilage: Development, differentiation, and growth. Vol 2, Bk Hall Ed, New York: Academic Press, pp 187-222,1983.
20. Luder HU. Postnatal Development, Aging, and Degeneration of the Temporomandibular Joint in Humans, Monkeys, and Rats. In: Craniofacial Growth Series, Vol.32. Centre for Human Growth and Development , The

University of Michigan, Ann Arbor, Michigan; 133-168.

21. Moss ML. The primacy of functional matrices on orofacial growth. Dent Pract 19:65;1968
22. Limborg J van: A new view on the control of the morphogenesis of the skull. Acta Morphol Neerl Scand 8:143;1970.
23. Ronning O, Koski K. The effect of the articular disc on the growth of the condylar cartilage transplants. Trans of the Eur Ortho Soc 45:99-107, 1969.
24. Thilander B, Carlsson G, Ingerval B. Postnatal development of the human temporomandibular joint. I. A histological study. Acta Odontol Scand 1976;34:117-126.
25. Duterloo HS, Jansen WB. Chondrogenesis and osteogenesis in the mandibular condylar blastema. Trans Europ Orthod Soc 1969:109-18.
26. Durkin JF, Heeley JD, Irving JT. The cartilage of the mandibular condyle . In: Temporomandibular joint function and dysfunction I . 29-99. Oral Sciences reviews, 2. Copenhagen, Munksgaard, 1973.
27. Mc Namara JA. Functional determinants of craniofacial size and shape. Eur J Orthod 1980;2:131-159.
28. Brodie AG. On the growth pattern of the human head. From the third month to the eight year of life. Am J Anat, 1941;68:209-262.
29. Brodie AG. Facial Patterns, a theme on variation. Angle Orthod 1946;16:75-87.
30. Sarnat BG. Growth of bones as revealed by implant markers in animals. Am J Phys Anthrop 1968;29:255-85.
31. Hunter CJ. The correlation of facial growth with body height and skeletal maturation at adolescence. Angle Orthod 36:44, 1966.
32. Riolo ML et al: An Atlas of Craniofacial Growth. Ann Arbor, 1974. University of Michigan, Center for Human Growth and Development.
33. Dibbets JMH, de Bruin, Van der Weele LT. Shape change in the mandible during adolescence. In: Craniofacial Growth During Adolescence. Carlson DS, Ribbens

KA. Ed. Ann Arbor, University of Michigan; 1987:69-85.

34. De Bont LGM, Stegenga B. Pathology of temporomandibular joint derangement and osteoarthrosis. Int J Oral Maxillofac Surg 1993;22:71-4.
35. Mohlin B, Pilley JR, Shaw WC. A survey of craniomandibular disorders in 1000 12 year-olds. Study design and baseline data in a follow-up study. Europ J Ortho. 1991;13:111-123.
36. Wanman A, Agerberg G.Temporomandibular joint sounds in adolescents: A longitudinal study. Oral Surg Oral Med Oral Pathol. 1990;69:2-9.
37. Heikinheimo K, Salmi K, Myllerniemi S, Kirveskari P. A longitudinal study of occlusal interferneces and signs of craniomadibular disorder at the ages 12 and 15 years. Europ J Ortho. 1990;12:190-197.
38. Nielsen L. Melsen B, Terp S. Prevalence, interrelation, and severity of signs of dysfunction from masticatory system in 14-16-year old Danish children. Comm Dent Oral Epidemiol 1989;17:91-96.
39. Kononen M, Nystrom M, Kleemol-Kujala E, Kataja M et al. Signs and symptoms of craniomandibular disordersin a series of Finnish children. Acta Odont Scand 1987;2:109-114.
40. De Boever JA, van den Berghe L. Longitudinal Study of functional conditions in the masticatory system in Flemish children. Comm Dent Oral Epidemiol 1987;15:100-3.
41. Meng HP, Dibbets JMH, van Der Weele LT, Boering G. Symptoms of temporomandibular joint dysfunction and predisposing factors. J Prosth Dent. 1987;57(2):215-222.
42. Dibbets JMH, van der Weele Lth. Prevalence of Structural Bony change in the Mandibular Condyle. J Craniomandib Disord Facial Oral Pain 1992;6:254-9.
43. Wanman A, Agerberg G. Two-year longitudinal study of symptoms of mandibular dysfunction in adolescents. Acta Odontol Scand. 1986;44:321-31.
44. Wanman A, Agerberg G. Mandibular Dysfunction in adolescents. II. Prevalence

of signs. Acta Odontol Scand. 1986;44:55-62.

45. Magnusson T, Egermark-Eriksson I, Carlsson G. Five-year Longitudinal Study of Signs and Symptoms of Mandibular Dysfunction in Adolescents. The J Craniomand Pract. 1986;4(4):338-44.
46. Nilner M. Functional Disturbances and Diseases in the Stomatognathic System among 7- to 18-Year-Olds. The J Craniomand Pract. 1985;3(4):359-67.
47. Wanman A, Agerberg G. Relationship between signs and symptoms of mandibular dysfunction in adolescents. Community Dent Oral Epidemiol. 1986;14:225-30.
48. Magnusson T, Egermark-Eriksson I, Carlsson G. Four-year longitudinal study of mandibular dysfunction in children. Community Dent Oral Epidemiol. 1985;13:117-20.
49. Ogura T, Morinushi T, Ohno H, Sumi K, et al. An epidemiollogical study of TMJ dysfunstion syndrome in adolescents. The J Pedodont. 1985;10:22-35.
50. Gazit E, Lieberman M, Eini R, Hirsch N et al. Prevalence of mandibular dysfunction in 10-18 year old Israeli schoolchildren. J Oral Rehab. 1984;11:307-17.
51. Nilner M, Lassing S. Prevalence of functional disturbances and diseases of the stomatognathic system in 7-14 year olds. Swed Dent J. 1981;15:173-87.
52. Egermark-Eriksson I, Carlsson GE, Ingervall B. Prevalence of mandibular dysfunction and orofacial parafunction in 7-, 11- and 15-year -old Swedish children. Europ J Ortho. 1981;3:163-72.
53. Solberg WK, Woo MW, Houston JB. Prevalence of mandibular dysfunction in young adults. JADA. 1979;98:25-34.
54. Helkimo M. Studies on function and dysfunction of the masticatory system. II. Index for anamnestic and clinical dysfunction and occlusal state. Swedish Dent J. 1974;67:101-26.
55. Egermark-Eriksson I, Carlsson GE, Magnusson T, Thilander B. A longitudinal

Study on malocclussion in relation to signs and symtoms of cranioamdibular disorders in children and adolescents. Europ J Ortho. 1990;12:399-407.

56. Lieberman MA, Gazit E, Fuchs C, Lilos P. Mandibular dysfunction in 10-18 year old school children as related to morphological malocclusion. J Oral Rehab. 1985;12:209-14.
57. Riolo ML, Brandt D, TenHave T. Associations between occlusal characteristocs and signs and symptoms of TMJ dysfunction in children and young adults. Am J Orthod Dentofac Orthop. 1987;92:467-77.
58. Egermark-Eriksson I, Carlsson GE, Magnusson T. A long term epidemiologic study of the relationship between occlusal factors and mandibular dysfunction in children and adolescents. J dent Res. 1987;66:67-71.
59. Dibbets JMH, Van der Weele LT, Boering G. Craniofacial Morphology and Temporomandibular Joint Dysfunction in Children. In: Developmental Aspects of Temporomandibular Joint Disorders. Carlsson DS, McNamara JA, Ribbens KA. (Eds).Monograph 16, Craniofacial Growth Series, Center for Human growth and Development, The University of Michigan, Ann Arbor, 1985;151-182.
60. Mintz SS. Craniomandibular dysfunction in Children and Adolescents: A review. J of Craniomand Practice. 1993;Vol 11 (3): 224-231.
61. Paesani D, Westesson PL, Hatala M, Tallents RH, Kurita K. Prevalence of temporomandibular joint internal derangement in patients with craniomandibular disorders. Am J Orthod Dentofac Orthop 1992;101:41-7.
62. Ishigaki S, Bessette RW, Maruyama T. The distribution of internal derangement in patients with temporomandibular dysfunction-prevalence, diagnosis, and treatments. J Craniomand Pract 1992;10:289-296.
63. Tallents RH, Katzberg RW, Murphy BS, Proskin H. Magnetic Resonance imaging findings in asymptomatic volunteers and symptomatic patients with temporomandibular disorders. J Prosthet Dent 1996;75:529-33.
64. Katzberg RW, Westesson PL, Tallents RH, Drake CM. Anatomic Disorders of the

Temporomandibular Joint Disc in Asymptomatic Subjects. J Oral Maxillofac Surg 1996;54:147-53.

65. Schiffman EL, Anderson GC, Fricton JR, Lindgren BR. The Relationship Between Level of Mandibular Pain and Dysfunction and Stage of Temporomandibular Joint Internal Derangement. J Dent Res 1992;71(11):1812-1815.
66. Keeling SD, McGorray S, Wheeler TT, King JK. Risk Factors associated with temporomandibular joint sounds in children 6 to 12 years of age. Am J Orthod Dentofac Orthop. 1994;105:279-87.
67. Rohlin M, Wesstesson Pl, Eriksson L. The correlation of temporomandibular joint sounds with joint morphology in fifty-five autopsy specimens. J Oral Maxillofac Surg 1985;43:194-200.
68. Roberts CA, Tallents RH, Katzberg RW, Sanchez-Woodworth Re et al. Clinical and Arthrographic evaluation of temporomandibular joint sounds. Oral Surg Oral Med Oral Pathol 1986;62:373-6.
69. Tallents Rh, Hatala M, Katzberg RW, Westesson PL. Temporomandibular joint sounds in asymptomatic volunteers. J Prosth Dent 1993;69:298-304.
70. Eriksson L, Westesson PL, Rohlin M. Temporomandibular joint sounds in patients with disc diplacement. Int J Oral Surg 1985;14:428-36.
71. Pullinger AG, White SC. Efficacy of TMJ radiographs in terms of expected versus actual findings. Oral Surg Oral Med oral Pathol Oral Radiol Endod 1995;79:367-74.
72. Sutton DI, Sadowsky Pl, Bernreuter WK, McCutcheon MJ et al. Temporomandibular joint sounds and condyle/disk relations on magnetic resonance images. Am J Orthod Dentofac Orthop 1992;101:70-8.
73. Dolwick FM, Dimitroulis G. A re-evaluation of the importance of disc position in temporomandibular disorders. Aus Dent J, 41(3):184-7;1996.
74. Westesson PL. Katzberg RW, Tallents RH et al. TMJ: comparison of MRI

images with cryosection anatomy. Radiology. 1987;164:59-64.

75. Tasaki MM, Westesson PL. Temporomandibular joint: diagnostic acurracy with sagittal and coronal MR imaging. Radiology 1993;186:723-9.
76. Hans MG, Lieberman J, Goldberg J, Rosencweig G et al. A comparison of clinical examination, history, and magnetic resonance imaging for identifying orthodontic patients with temporomandibular joint disorders. Am J Orthod Dentofac Orthop. 1992;101:54-9.
77. Westesson PL, Eriksson L, Kurita K. Reliability of a negative clinical temporomandibular joint examination: Prevalence of disk displacement in asymptomatic temporomandibular joints. Oral Surg Oral Med Oral Pathol. 1989;68:551-4.
78. Drace JE, Enzmann DR. Defining the Normal Temporomandibular Joint: Closed-, Partially Open-, and Open-mouth MR Imaging of Asymptomatic Subjects. Radiology.1990;177:67-71.
79. Lieberman JM, Hans MG, Rozencweig G, Goldberg HS et al. MR Imaging of the juvenile Temporomandibular Joint: Preliminary report . Radiology 1992;182:531-4.
80. Petrovic A, Stutzman J, Oudet C. Control processes in the postnatal growth of the mandibular condylar cartilage. In McNamara JA ed. : Determinants of Mandibular Form and Growth. Monograph No. 4 , Craniofacial Growth Series, Center for Human Growth and Development, The University of Michigan, Ann Arbor, Michigan, USA.
81. Nickerson JW, Boering G. Natural Course of Osteoarthrosis as it relates to Internal derangement of the Temporomandibular Joint. Oral Maxillofac Clinics North Amer. 1989;1(1):27-45.
82. Stringert HG, Worms FW. Variations in skeletal and dental patterns in patients with structural and functional alterations of the temporomandibular joint:A preliminary report. Am J Orthod. 1986;89:285-97.

83. Link JJ, Nickerson JW. Temporomandibular joint internal derangements in an orthognathic surgery population. Int J Adult Orthod Orthognath Surg 1992;7:161-9.

84. Potter GD, Palmer RP. Radiographic Analysis of the Skull. Dental Radiography and Photography. 1976;49:27-39.

85. Major PW, Johnson DE, Hesse KL, Glover KE. Landmark identification error in posterior anterior cephalometrics. Angle Orthod 1994;64:447-54.

86. Major PW, Johnson DE, Hesse KL, Glover KE. Effect of head orientation on posterior anterior cephalometric landmark identification. Angle Orthod 1994;66:51-60.

87. Houston WJB. The analysis of errors in orthodontic measurements. Am J Orthod 1983;83:382-90.

88. El Mangoury NH, Shaheen SI, Mostafa YA. Landmark identification in computerized posteroanterior cephalometrics. Am J Ortho Dentofac Orthop 1987;91:57-61.

89. Harvold EP, Trugue M, Viloria JO. Establishing the median plane in posteroanterior cephalograms.

90. Lund K. Mandibular growth and remodelling processes after condylar fracture. A longitudinal roentgencephalometric study. Academic dissertation. Acta Odontol Scand 32:suppl. 64:

91. Mulick JF. An investigation of craniofacial asymmetry using the serial twin-study method. Am J Orthod 1965;51:112-29.

92. Letzer GM, Kronman JH. A posteroanterior Cephalometric Evaluation of Craniofacial Asymmetry. Angle Orthod 1967;37:205-11.

93. Hewitt AB. A radiographic Study of Asymmetry. Brit J Orthod 1974;2:37-40.

94. Vig PS, Hewitt AB. Asymmetry of the Human Facial Skeleton. Angle Orthod 1975;45:125-9.

95. Shah SM, Joshi MR. An assessment of Asymmetry in the Normal Craniofacial

Complex. Angle Orthod 1978;48:141-8.

96. Cook JT. Asymmetry of the Cranio-facial Skeleton. Brit J Orthod 1980;7:33-8.

97. Chebib FS, Chamma AM. Indices of Craniofacial Asymmetry. Angle Orthod 1981;51:214-26.

98. Butow KW, van der Walt PJ. The "Stellenbosch"-triangle analysis of the postero-anterior and basilar cephalograms. J Dent Assoc South Africa 1981;36:461-7.

99. Grayson BH, McCarthy JG, Bookstein F. Analysis of craniofacial asymmetry by multiplane cephalometry. Am J Orthod 1983;217-24.

100. Grummons DC, Kappeyne van de Coppelo MA. A Frontal Asymmetry Analysis. JCO 1987;21:448-65.

101. Mongini F, Schmid W. Treatment of mandibular asymmetries during growth. A longitudinal study. Europ J Orthod 1987;9:51-67.

102. Alavi D, BeGole E, Schneider BJ. Am J Orthod Dentofac Orthop 1988;93:38-46.

103. Stabrun AE. Mandibular morphology and position in juvenile rheumatoid arthritis. A study on posteroanterior radiographs. Europ J Orthod 1985;7:288-98.

104. Johnston DE. The posteroanterior cephalometric radiograph. Masters Thesis 1991:pp46.

105. Bishara SE, Burkey PS, Kharouf JG. Dental and facial asymmetries: a review. Angle Orthod 1994;64:89-98.

CHAPTER II

FIRST RESEARCH STUDY AND RESULTS

VERTICAL AND TRANSVERSE CRANIOFACIAL DIMENSIONS IN PREORTHODONTIC ADOLESCENTS WITH TMJ INTERNAL DERANGEMENT

2.1 INTRODUCTION

Osseous pathology of the temporomandibular joint (TMJ) may lead to mandibular growth disturbances.[1,2] Also, TMJ dysfunction is associated with certain craniofacial morphologies such as asymmetry, Class II malocclusion, deep bite and open bite. [3] Investigations of skeletal and dental patterns on adult patients with TMJ soft tissue abnormalities have shown a significant decrease in maxillary and mandibular body length in patients with TMJ internal derangement (ID). [4,5] Sagittal maxillary and mandibular deficiency has been also demonstrated in patients with signs and symptoms of TMJ dysfunction who were followed from childhood to adulthood. [6] Reported variations of vertical dimensions include decreased posterior facial height, hyperdivergent skeletal pattern and increased horizontal discrepancy. [4] The work of Dibbets [7,8] raised important questions regarding craniofacial morphology and the presence of TMJ disorders in juvenile patients. Children with deformed condyles evident on radiographs were more retrognathic and showed a smaller overall length of the mandible, shorter posterior facial height, shorter ramus and shorter corpus, larger gonial angle and steeper mandibular plane. More recently Nebbe et al. [9] reported decreased ramus height and total posterior facial height in adolescent patients with TMJ disc displacement.

Several authors have described significant associations between mandibular retrognathism in orthognathic surgery patients and TMJ internal derangement. [10-12] Similar findings in pediatric population have led the authors to postulate that TMJ internal derangement causes significant abnormal mandibular growth and associated malocclusion.[13]

TMJ internal derangement is a common clinical finding in adolescents. It is often ignored by the patients because it is usually not accompanied by pain or impaired mandibular function.[14] Age and gender differences in TMJ ID are found in postpubertal in contrast to prepubertal children, suggesting that changes during adolescence may be linked to the appearance of TMJ dysfunction.[15] This change is more significant in girls; hormonal factors as well as maturation of the occlusion have been suspected as contributing factors.[15]

TM joints showing radiographic deformation of the condyle are highly correlated with anteriorly displaced discs without reduction. [12] This finding implies that advanced disc displacement without reduction is a possible precursor of condylar osteoarthrosis. Initiating factors for the internal derangement may be substandard collagen structure, adverse loading, decreased synovial fluid production and biochemical alterations of synovial fluid, inflammatory mediators, metabolic changes in collagen, trauma, hypermobility or instability. Whether TMJ ID in absence of osteoarthrosis can impact mandibular growth remains unknown. [16] Scientific evidence to date does not support the assumption that disc displacement with reduction progresses towards disc displacement without reduction and osteoarthrosis. However, a joint that is internally deranged is physically abnormal and may impede mandibular growth. [17] Disc displacement may lead to a failure to achieve full mandibular growth potential or to subtraction of already achieved growth in an older individual.[12]

Previous studies that have investigated TMJ disc displacement utilized lateral cephalograms to demonstrate sagittal cranifacial dimensions. [4-6,8,9] Unfortunately, lateral cephalometry limits the observations to averaged vertical dimensions while transverse measurements remain unexplored. The only study that correlated craniofacial morphology with TMD used clinical and radiographic findings to establish TMJ

dysfunction. [7] Clinical evaluation of TMJ internal derangement lacks sensitivity and specificity in identifying TMJ disc displacement. Approximately 50% of the patients with an abnormal condyle-disc relationship may be undetected if clinical examination is used. [18] Diagnosis of TMJ disc displacement requires an imaging technique that can accurately depict the soft parts of the joint. Magnetic resonance imaging (MRI) has been demonstrated to have both high sensitivity and specificity in establishing TMJ disc position and shape. [19-22] Moreover, MRI is not an invasive technique and is associated with minimal side effects. [23]

The objective of this study was to determine the relationship between TMJ ID and transverse and vertical craniofacial dimensions in adolescent patients. Craniofacial measurements taken from posteroanterior cephalograms were correlated with TMJ disc displacement evaluated with magnetic resonance imaging (MRI). We also investigated whether patients with unilateral or bilateral TMJ ID have different craniofacial size compared to individuals with normal TMJ-s.

2.2 MATERIALS AND METHODS

2.2.1 Sample

The sample included in this investigation consisted of consecutive patients presenting to a private orthodontic practice and the Graduate Orthodontic Clinic at the University of Alberta, along with patients suspected of having TMJ internal derangement referred by orthodontists from the Edmonton area. Patients included were without history of trauma, infection, tumours, rheumatic disease or other clinically relevant pathology. Posterior-anterior radiographs were obtained using a Siemens OP10 x-ray machine with standardized exposure. A cephalostat ensured head positioning with Frankfort horizontal parallel to the floor. Source to earrod distance was 60 inches and ear rod to film distance was 5 inches.

Bilateral temporomandibular joint magnetic resonance images were obtained at the Magnetic Resonance Centre of Edmonton using 1.0 Tesla machine (Shimadzu Corporation 3, Kanda-Nishikicho 1-chrome, Chiyoda-Ku, Tokyo, Japan). Mandibular position was secured in centric occlusion with polyvinylsiloxane bite registration (President Jet-Bite, Coltane/Whaledent Inc., Mahwah, New Jersey). Bilateral closed mouth sagittal sections perpendicular to the condylar long axis were obtained with a unilateral 3-inch surface receiver coil. T1-weighted 500/20 (TR ms/TE ms) pulse sequences were performed, using a 3 mm slice thickness, 140 mm field of view, NEX of 2, and an image matrix of 204x204.

The records of one hundred and thirty-seven preorthodontic patients, comprised of eighty females (mean age 13.20 years, SD 1.70, range 10.01 to 16.64 years) and fifty-seven males (mean 13.26 years, SD 1.84, range 9.57 to 17.09 years) were available for this study.

2.2.2 Cephalometric Analysis

Posterior-anterior cephalograms were used for cephalometric analysis of vertical and transverse proportions. All radiographs were traced twice by one observer on a transparent acetate paper with a 0.3mm 3H pencil. The choice of landmarks was based on previously published PA cephalometric reproducibility studies.[24] Landmark registration was performed manually. Six bilateral skeletal and one dental bilateral points were identified. (Figure 2.1). Orbita tangent (OT) was drawn to represent the horizontal reference line. A vertical reference line, i.e., facial midline (FM) was constructed as a line passing through the midpoint of a line drawn between the intersections of the greater wing of the sphenoid bone and the orbital margin (GWSO), perpendicular to the OT. The landmarks, distances and reference lines used are listed in Table 2.1.

From each landmark, perpendicular lines were drawn to the constructed reference system amounting to a total of seven vertical and seven horizontal measurements per side (right and left) for each tracing. In addition, ramus height was measured on each side as the distance from the most superior point of the condyle to the antegonial notch (Figure 2.1).

2.2.3 MRI Analyses

Quantitative measures of disc displacement and disc length were obtained of sagittal MRI slices using the procedure described by Nebbe et al. [25] On each MRI slice tracing a reference plane was drawn as a line intersecting the transferred Frankfort horizontal at 50 degrees through a point 10 mm anterior to the maximum height of the articular fossa (Figure 2.2). Three landmarks were identified on the articular disc: anterior band, posterior band and midpoint of the disc. The condylar load point (CLP) was determined on the head of the condyle at the shortest distance from the articular portion of the

glenoid fossa. Perpendicular lines were erected from each landmark to the reference line (Figure 2.3). Disc displacement was measured as the distance from the midpoint of the disc to the CLP. A negative value for disc displacement implied that the midpoint of the disc was posterior to the CLP and was considered a variant of normal. Disc length was measured as the distance from the anterior to the posterior band along the reference line. Based on previous finding that established negative association between disc length and disc displacement [25] it was decided to produce a positive correlation between these variables. The disc length measurements were subtracted from an average value for a normal disc length of 10 mm. The values obtained ranged from negative values, representing disc length greater than 10 mm and therefore normal, to positive values, describing disc shortening of increasing severity. In this way several variables measuring disc displacement and disc length were obtained per joint. Rather than calculating a mean value of these variables, the total number of measurements for each joint was integrated into a single weighted score for all disc displacement and one for all disc length variables by using principal components analysis (SPSS for Windows, SPSS Inc. Chicago, IL). The same statistical procedure was used to synthesize disc displacement and disc length scores into one total score for Temporomandibular Joint Internal Derangement for each side (TMJID Right; TMJ ID Left).

2.2.4 Method Error

Intra-observer reproducibility - Cephalometry

Ten PA cephalograms were randomly selected, coded, and traced five times by the principal observer under the same conditions, with a minimum of one week between tracings. Multivariate ANOVA procedure with cephalometric measurements and tracings as factors was used to measure the significance of variability between tracings, expressed as F-statistics. Observer reliability was estimated as a coefficient of reliability [26] that was calculated as Rel= 1-1/F for each cephalometric measure. This score is a measure of

between tracing variability within patient (homogeneity of measurements obtained from five replicated tracings) relative to the total variability for the measurement between patients.

Intra-observer reproducibility - MRI

Ten MRI-s representing normal disc position and ten representing disc displacement were selected and randomly traced five times on consecutive days. Multivariate ANOVA procedure with MRI tracings as factors produced F-statistics which were used to calculate a coefficient of intra-rater reliability Rel=1-1/F for disc length and disc displacement. In addition, standard error deviation and range were calculated according to Dahlberg's formula for repeated measurements. [27]

Measurement error

Each cephalogram was traced twice on separate occasions. Dahlberg's formula [27] was used to quantify the standard error for replicated measures as mean, standard deviation and range of standard error expressed in millimetres.

2.2.5 Statistical Methods

1. The effect of age on craniofacial measurements and TMJ ID data was evaluated with multiple linear regression analysis. The assumption of linearity between the tested variables was violated at the start due to the non-linear relationship between age and craniofacial growth. Polynomial regression techniques were used to avoid this problem.[28] Multiple linear regression equations were fitted with age and its quadratics age^2 and age^3 as independent variables and each craniofacial measurement and TMJ ID measure as dependent variables for females and males separately. If found significant,

variability due to age or its quadratics was eliminated by mathematical transformation. The sum of B-constant value and the unexplained portion of the tested variable were added to produce new quadratic craniofacial or TMJ ID variables for further multiple linear regression tests.

2. Multiple linear regression analysis was used to study the relationship between:

a. TMJ ID R as dependent variable and all right side craniofacial measurements as independent variables

b. TMJ ID L as dependent variable and all left side craniofacial measurements as independent variables

All variables were initially included in the regression model, but in the final outcome only those variables most likely to explain the dependent variable were retained. Multiple linear regression includes in the outcome the one variable out of several highly correlated with each other that adds to the regression equation the most. Pearson correlation coefficients were also calculated for all craniofacial measurements to search for clinically meaningful information potentially masked by the multiple regression outcome.

3. To assess the clinical significance of unilateral or bilateral TMJ internal derangement, a cluster analysis was performed to group the patient sample with regard to severity and location (unilateral or bilateral) of TMJ ID using:

- R-L -- difference between TMJ ID score within patient
- R+L -- sum of bilateral TMJ ID score within patient

In this way four categories of patients were produced:

I. Bilateral normal TMJ-s; close to zero R-L and close to zero R+L score.

II. TMJ ID on the right side more severe than on the left; positive R-L score and positive R+L score.

III. TMJ ID on the left side more severe than on the right; negative R-L score and positive R+L score

IV. Bilateral ID of approximately equal severity; R-L score close to zero and positive R+L score.

4. A one-way ANOVA statistic was used to compare mean values for each craniofacial measure between the four categories of patients and to test whether significant differences existed regardless of age difference. The effect of age upon craniofacial measurements was tested using multivariate ANOVA (MANOVA) statistics with age as a covariate and all craniofacial measurements as dependent variables.

The statistical significance level for all analyses was set at $p < 0.05$.

2.3 RESULTS

Intra-observer reproducibility results are listed in Table 2.2. The closer the value of the coefficient of reliability is to one, the greater is the intraobserver reliability. Coefficient values over 0.8 can be considered reliable. Coefficients of reliability in this study ranged from 0. 8798 for Right J-FM to 0.9988 for both Left and Right Ma-OT. Intra-observer MRI reproducibility results were also consistent; maximum standard deviation of measurement error in determination of disc length and disc displacement were less than 0.5 mm as presented in Table 2.3. Measurement of error expressed as standard error mean, standard deviation of the mean, and minimum and maximum recorded values for each craniofacial variable are listed in Table 2.4.

The following variables were significantly related to age, age ^{2} and age ^{3}:

1. TMJ ID score on the left side in the male group only
2. AgL-FM, JL-FM, MaL-FM, MolL-FM and ZyL-FM in males and
3. MaR-OT, MolR-OT, Ramus R, Ramus L and ZyL-FM in females.

These variables were notified as quadratic variables and marked with the * symbol.

Tables 2.5 and 2.6 contain the outcome of the multiple linear regression tests for TMJ ID R and TMJ ID L as dependent variables and all craniofacial measurements as independent variables. Only the significant craniofacial measurements are reported. The adjusted R square values are a numerical measure of the percentage of TMJ ID variability explained by these craniofacial parameters. Pearson correlation coefficients denote the association between all craniofacial measures and TMJ ID scores with the variables included in the regression outcome. (Table 2.7)

Patient classification according to cluster analysis is presented in Table 2.8. One way ANOVA results comparing means of cluster groups are shown independently for females

and males in Tables 2.9 and 2.10. MANOVA outcome showed that age was a significant covariate for the following measurements in the female group: AgL-OT, AgR-OT, AgR-FM, CoCL-FM, CoCR-FM,CoSR-FM, CoSL-FM, MolL-OT, MolR-OT, Ramus R, Ramus L, ZyL-FM and ZyR-FM. After removing the effect of age AgR-OT (p-value 0.008) and Ramus R (p-value 0.044) were significantly different between the four cluster categories. In the male sample, all variables except for MolL-FM and CoSL-OT were significantly affected by age. No significant mean differences were found in the male sample after removing the age effect.

Figures 2.4 and 2.5 represent a summary of the results from this study for females and males respectively.

2.4 DISCUSSION

Interpretation of TMJ internal derangement is usually accomplished using subjective classification. Varying degrees of disc displacement with reduction, disc displacement without reduction and disc deformation can be recognized on MRI. [29-33] In this study we used an objective measure of internal derangement developed by Nebbe et al. [25] The resultant TMJ ID score represents a composite value of the degree of disc shortening and disc displacement measured from a reference point (condylar loading point). The TMJ ID score is therefore an objective measure of a structural TMJ abnormality. Increase in the TMJ ID score indicates greater TMJ soft tissue abnormality.

Multiple linear regression analysis has been used in cephalometric research, [7,9] and its validity for cephalometric analysis has been examined recently. [34] Using this method, patient division into smaller groups was avoided, which increased the ability to detect relations between the dependent variable (TMJ ID) and multiple independent variables (craniofacial measurements). Adjusted R^2 values multiplied by 100 express the percentage of TMJ ID variability explained by related craniofacial variables. Overall, mandibular variables emerged as valuable in explaining TMJ ID. Also, vertical as opposed to transversal mandibular parameters were significant in explaining TMJ ID (Tables 2.5 and 2.6). In females, the right and the left side showed different adjusted R square values (Table 2.5). Ramus height on both sides decreased with an increase of TMJ ID. On the right side the vertical height from the condyle to the cranial reference line was shorter in patients with internal derangement which is consistent with recent report of reduced posterior cranial base height. [35] A significant correlation was noted between the vertical position of the condyle, maxillary base and ramus height with the vertical position of the mandibular angle (AgR-OT, Table 2.7). This explains why AgR-OT was not included in the regression outcome. The vertical distance from the maxillary base (JR) to the cranial base reference line OT was shorter on the right side. It is possible

that the maxilla grows to counteract the lack of mandibular growth in attempt to maintain vertical growth. The first maxillary molar was also positioned farther from the cranial base reference indicating possible dental compensation. The findings were different in the male sample; there were no craniofacial parameters significant in explaining the variability of R TMJ ID, while on the left side three mandibular parameters were significant in explaining 10% of the TMJ ID variable. According to this outcome, posterior facial height shortened as TMJ ID score increased. The relative vertical position of the center of the condyle decreased while the relative vertical position of the superiormost point of the condyle increased with TMJ ID increase. Provided patient numbers were sufficient this could be interpreted as change in condylar size or "flattening" of the condyle. However, this finding must be interpreted in view of the low R squared value and the very small numbers of TMJ ID in the male sample. Similar to the female group, the males showed that maxillary base and maxillary first molar were highly correlated with significant variables. It should be emphasized that numerous other factors are responsible for the growth rate, direction and amount of growth of the condyle, and the adjusted R squared values were not expected to be high. The adjusted R squared values for TMJ ID on the right side in females can be considered significant since they represent the single contribution of craniofacial dimensions in explaining the TMJ ID.

Nebbe et al. [35] demonstrated reduced ramus height and reduced posterior cranial base height associated with TMJ disc abnormality on lateral cephalograms. When female patients with advanced bilateral ID (total disc displacement) were compared with patients with bilateral normal joints, total posterior face height was shorter by 5.57mm while ramus height was 4.18 mm less in the deranged group. The same pattern was identified using a multiple linear regression analysis. Therefore, the height of the ramus contributed significantly to reduction in posterior facial height. However, lateral cephalometric analysis has several limitations. Left and right craniofacial dimensions cannot be adequately identified and have to be averaged. The relative contribution of left versus

right TMJ abnormality cannot be established. By using posteroanterior cephalograms we were able to analyse the left and right sides of the face separately and relate the findings to the status of the left and right joints independently. If TMJ ID does have an effect on mandibular growth and development, patients with unilateral TMJ ID should show an ipsilateral reduction of mandibular dimensions. Out of thirty craniofacial parameters, only one showed significant difference between the four cluster groups, AgR-OT in females and MaL-FM in males (Tables 2.9 and 2.10). Females with bilateral TMJ ID had significantly shorter (7.2mm) posterior face height (AgR-OT) on the right side as compared with females with bilateral normal or unilateral left ID. Female patients with unilateral left TMJ ID had almost identical mean value for AgR-OT as females without TMJ ID, a result which supports the supposed association of TMJ ID with mandibular size. Females with unilateral right TMJ ID had a mean value for posterior face height 2.5mm less than patients with bilaterally normal joints, which was not statistically significant. The MANOVA results confirmed previously revealed trends. Once the effect of age was eliminated, posterior facial height and ramus height on the right side in females showed significant differences between the cluster groups.

The results of this study in the male sample have to be interpreted cautiously. As seen in Table 2.9 the number of males with TMJ ID was lower than in females, which is consistent with epidemiologic surveys that report greater prevalence of TMJ ID in females. [36-40] In the male sample only 13 out of 57 patients had internal derangement and only 2 male patients had bilateral ID. The only measurement significantly different was the transverse distance from the left mastoid process to facial midline (MaL-FM). It is unlikely that the transversal position of the mastoid process could be related to TMJ ID. Also, the lack of adequate sample size and the effect of age likely contributed to the observed mean differences in the male sample (Table 2.10).

According to our results, a bilateral TMJ ID may have a more pronounced effect upon

vertical mandibular growth on both sides of the face than unilateral ID on the ipsilateral side. It is possible that altered functional balance as a result of bilateral TMJ ID may affect craniofacial morphology to a greater extent than the local disturbance. Evidence of adjusted condylar growth in a growing individual as a result of an altered functional environment has been experimentally established. [41] The degree to which a TMJ disorder can influence facial growth will depend on the time of onset, the duration of the condition and the severity of the dysfunction. An unknown factor is the time of onset of TMJ ID in these patients, as well as the primary side affected by internal derangement. If the TMJ ID involves the right side first, the pronounced effect in patients with bilateral ID on the right side could be due to longer existence of a structural problem within the right joint compared to left.

The only previous study using posteroanterior cephalograms to assess association between temporomandibular disorders and craniofacial dimensions was reported by Dibbets. [7] In approximately one out of three patients with radiographic diagnosis of juvenile arthrosis the left gonial notch was positioned higher than the right which resulted in clinically observable asymmetry. Cephalometric analysis did not reveal osseous asymmetry. He did not demonstrate an influence of TMJ dysfunction upon vertical and transversal proportions from PA analysis. It is also important to emphasize that in Dibbets' study disc status was not objectively assessed and its outcome cannot be directly compared to that in our study.

The postero-anterior (PA) cephalogram accommodates the right and left structures at a relatively equal distance from the film and source. Technical difficulties due to disproportionate projection errors are therefore minimized. As with any cephalometric analysis, there is a risk for error inherent to the method that was used. Intra-observer reliability was adequate (Table 2.1). Due to tissue superimposition, it is difficult to clearly trace the head of the condyle on a PA cephalogram. This resulted in larger

measurement error for CoC-OT, CoS-OT and Ramus height. However, Ag-OT had an acceptable error (Table 2.4).

The majority of adolescents included in our investigation were a selection of preorthodontic patients with a variety of craniofacial and occlusal patterns. In view of the sample characteristics, it must be emphasized that our findings are limited to the average patient that presents for orthodontic treatment.

It has been suggested that the presence of TMJ dysfunction may result in the development of significant facial deformities. [10-13] These studies have included preselected patients referred for orthognathic correction of skeletal deformities. Also, these investigations have described craniofacial morphology but have not included statistical analyses. According to the results of this study, there is no reason for concern that a patient with TMJ ID may develop a significant transverse abnormality. Results of this study demonstrated an association between TMJ internal derangement and vertical dimensions of the mandible. Females with bilateral TMJ ID may develop mandibular vertical asymmetry, and therefore should be monitored for such changes. It remains unknown whether this deviation from normal mandibular dimensions will progress or resolve over time.

2.5 SUMMARY AND CONCLUSIONS

The results of this investigation did not reveal a characteristic growth pattern in vertical and transverse proportions in adolescents with TMJ ID, which would distinguish them from their peers with normal TMJ-s. In females, shorter projected ramus height on the right side was found in patients with bilateral TMJ ID, as compared to individuals with bilaterally normal TMJ-s and patients with unilateral left TMJ ID. This finding suggests that bilateral TMJ ID in a young female patient is more likely to be associated with altered mandibular growth. In males with TMJ ID, there were no recognizable patterns of craniofacial morphology.

Table 2.1.

Cephalometric Landmarks and Reference Lines	
Bilateral Landmarks	
Zy	Zygomatic point- the most lateral aspect of the zygomatic arch
Ma	Mastoid Point- the most inferior point on the mastoid process
CoS	Condyle Superior- the most superior aspect of the mandibular condyle
CoC	Condyle Center- the center of the mandibular condylar head
JP	Jugal Point- the deepest point on the curve of the malar process of the maxilla
Ag	Antegonion- the deepest point on the curvature of the antegonial notch
Mol	Molare- the midpoint of the buccal surface of the maxillary first molar
Mandibular Ramus Height	
Ramus R	the distance from the superiormost point on the outline of the right mandibular condyle to the ipsilateral antegonion (CoSR-AgR)
Ramus L	the distance from the superiormost point on the outline of the left mandibular condyle to the ipsilateral antegonion (CoSL-AgL)
Horizontal reference line	
OT	Orbita Tangent, the line connecting the uppermost points on the superior outline of the right and left orbits
Vertical reference line	
FM	Facial midline -The perpendicular to the orbita-tangent line drawn through the midpoint of the distance between the right and left GWSO
GWSO	Greater Wing Superior Orbit - intersection of the superior border of the greater wing of the sphenoid bone and the orbital outline

Table 2.2. Coefficients of Intra-observer Reliability of Lateral Cephalometric Measurements

Measurement	Coefficient of reliability-Left Side	Coefficient of reliability-Right Side
Ag-FM	0.9836	0.9602
Ag-OT	0.9979	0.9982
CoC-FM	0.9928	0.9968
CoC-OT	0.9984	0.9929
CoS-FM	0.9799	0.9943
CoS-OT	0.9987	0.9932
J-FM	0.9119	0.8798
J-OT	0.9846	0.9742
Ma-FM	0.9962	0.9941
Ma-OT	0.9988	0.9988
Mol-FM	0.9786	0.9664
Mol-OT	0.9945	0.9941
Zy-FM	0.9960	0.9983
Zy-OT	0.9904	0.9791
Ramus	0.9969	0.9903

Table 2.3. MRI Reproducibility Results. Coefficients of Reliability, Standard Error's Maximum and Minimum Standard Deviation

Variables	Rel=1-1/F	Maximum SD	Minimum SD
Disc Displacement	1.00	0.33 mm	0.05mm
Disc length	0.98	0.47mm	0.07mm

Table 2.4. Cephalometric Measurements' Standard Error, as Estimated from Replicated Tracings.

Variable	Right Side				Left Side			
	mean	SD	Min	Max	Mean	SD	Min	Max
Ag-FM	0.50	0.42	0.01	2.50	0.56	0.43	0.00	2.60
Ag-OT	0.48	0.43	0.01	3.38	0.54	0.49	0.01	3.10
CoC-FM	0.58	0.59	0.01	3.61	0.58	0.60	0.00	2.73
CoC-OT	1.00	1.14	0.01	4.93	0.90	0.99	0.01	4.36
CoS-FM	0.71	0.74	0.02	4.17	0.66	0.66	0.01	2.62
CoS-OT	1.00	1.20	0.01	5.23	1.51	1.39	0.00	6.28
J-FM	0.58	0.61	0.01	4.01	0.64	1.36	0.00	16.32
J-OT	0.74	0.81	0.01	5.92	0.71	0.58	0.01	4.25
Ma-FM	0.40	0.44	.00	3.08	0.4	1.48	0.00	17.90
Ma-OT	0.32	0.29	0.00	1.77	0.33	0.31	0.01	2.09
Mol-FM	0.38	0.40	0.00	2.14	0.45	0.64	0.01	3.77
Mol-OT	0.49	0.65	0.01	5.31	0.49	0.50	0.00	3.13
Zy-FM	0.27	0.59	0.00	6.82	0.37	0.68	0.01	5.28
Zy-OT	0.48	0.41	0.00	2.26	0.71	1.86	0.01	21.82
Ramus	1.19	1.28	0.01	6.43	1.21	1.16	0.01	5.87

Table 2.5. Multiple Linear Regression Results for TMJ Score and Ipsilateral Facial Dimensions. Females

Dependent variable TMJ ID Right Side				Dependent variable TMJ ID Left Side			
Measurement	**P value**	**Correl. coeff.**	**R square**	**Measurement**	**P value**	**Correl. coeff.**	**R square**
CoCR-OT	.0003	-0. 197	0.22 (22%)	Ramus L*	.0028	-0.326	0.09 (9%)
JR-OT	.0003	0.136					
Ramus R*	.0002	-0.265					

*signifies quadratic variable, i.e., transformed variable free of the effect of age

Table 2.6. Multiple Linear Regression Results for TMJ Score and Ipsilateral Facial Dimensions. Males

Dependent variable TMJ ID Right Side			Dependent variable TMJ ID Left Side*			
Measurement	**P value**	**R square**	**Measurement**	**P value**	**Correl coeff.**	**R square**
None			CoCL-OT	.0073	-0.025	0.10 (10%)
			CoSL-OT	.0098	0.116	
			AgL-OT	.0309	-0.083	

*signifies quadratic variable, i.e., transformed variable free of the effect of age

Table 2.7. Correlation Coefficients Between Significant Variables in the Multiple Linear Regression Outcome and All Other Cephalometric Distances and Ipsilateral TMJ ID Score

Variable	Females			Variable	Females	Males		
Right Side	CoCR-OT	JR-OT	Ramus R	Left Side	Ramus L	CoCL-OT	CoSL-OT	AgL-OT
AgR-FM	0.026* -0.241	0.212 0.136	0.118 0.170	AgL-FM	0.222 0.133	0.324 -0.130	0.494 -0.090	0.391 -0.113
AgR-OT	0.000* 0.509	0.000* 0.375	0.000* 0.463	AgL-OT	0.000* 0.486	0.000* 0.581	0.000* 0.491	1.000
CoCR-FM	0.301 -0.113	0.198 0.140	0.000* 0.402	CoCL-FM	0.001* 0.363	0.159 0.185	0.499 0.089	0.001* 0.412
CoCR-OT	1.000	0.000* 0.467	0.641 -0.051	CoCL-OT	0.166 -0.151	1.000	0.000* 0.943	0.000* 0.581
CoSR-FM	0.182 -0.146	0.255 0.124	0.000* 0.412	CoSL-FM	0.001* 0.358	0.114 0.207	0.406 0.110	0.001* 0.438
CoSR-OT	0.000* 0.990	0.000* 0.433	0.348 -0.103	CoSL-OT	0.576 -0.061	0.000* 0.943	1.000	0.000* 0.491
JR-FM	0.667 0.047	0.176 0.148	0.722 0.039	JL-FM	0.067 0.199	0.844 -0.026	0.812 0.031	0.320 -0.131
JR-OT	0.000* 0.467	1.000	0.015* 0.262	JL-OT	0.007* 0.289	0.000* 0.440	0.006* 0.356	0.000* 0.789
MaR-FM	0.723 -0.039	0.780 0.030	0.017* 0.257	MaL-FM	0.577 0.061	0.753 -0.041	0.881 0.019	0.582 0.073
MaR-OT	0.000* 0.781	0.000* 0.416	0.915 0.011	MaL-OT	0.983 -0.002	0.000* 0.759	0.000* 0.418	0.000* 0.666
MolR-FM	0.097 -0.181	0.054* -0.209	0.365 0.099	MolL-FM	0.342 0.104	0.518 -0.085	0.971 -0.004	0.080 -0.229
MolR-OT	0.000* 0.447	0.000* 0.832	0.000* 0.447	MolL-OT	0.000* 0.373	0.000* 0.455	0.005* 0.357	0.000* 0.854
ZyR-FM	0.976 0.00	0.021* 0.250	0.001* 0.343	ZyL-FM	0.054* 0.210	0.373 0.118	0.134 0.197	0.936 -0.010
ZyR-OT	0.000	0.000*	0.734	ZyL-OT	0.899	0.000*	0.000*	0.000*

	0.813	0.502	0.037		-0.013	0.758	0.734	0.599
Ramus R	0.641 -0.051	0.015* 0.262	1.000	**Ramus L**	1.000	0.927 -0.012	0.942 0.009	0.000* 0.493
TMJ ID R	0.074 -0.197	0.220 0.136	0.015* -0.265	**TMJ ID L**	0.003* -0.326	0.849 -0.025	0.381 0.116	0.532 -0.083

upper value represents p-values; * notifies p-values < 0.05

lower value represents correlation coefficient; sign signifies positive or negative correlation

Table 2.8. Cluster Groups Formed by Combining TMJ ID Scores as Estimated with MRI

	FEMALES			MALES			
TMJ ID Category	Number of patients (%)	R-L Cluster Center	R+L Cluster Center	Number of patients (%)	R-L Cluster Center	R+L Cluster Center	Total
I.Bilateral Normal TMJ	42 (52.5%)	-0.124	-1.3414	44 (77.19%)	0.0396	-0.8135	77
II. Unilateral R TMJ ID	13 (16.25%)	1.2534	0.5919	7 (12.2%)	1.4803	2.0380	33
III. Unilateral L TMJ ID	10 (12.5%)	-1.5612	0.7210	4 (7.01%)	-2.8809	2.5836	22
IV. Bilateral TMJ ID	15 (18.75%)	-0.631	2.9246	2 (3.5%)	0.5403	4.7660	15
Total	80			57			137

Table 2.9. Comparison of Cluster groups I, II, III and IV for All Craniofacial Dimensions Derived from Bilateral Horizontal and Vertical Measurements. One-way ANOVA Results for Females.

Measurement	F prob.	I	II	III	IV	Category difference
AgL-FM	0.838	41.46	41.56	41.11	40.63	
AgL-OT	0.458	102.03	99.3	101.58	100.13	
AgR-FM	0.310	40.76	42.25	42.15	41.25	
AgR-OT	0.022*	101.38	98.98	101.53	94.14	IV from land III
CoCL-FM	0.617	49.58	50.38	48.68	49.11	
CoCL-OT	0.292	46.55	44.25	47.07	45.86	
CoCR-FM	0.419	49.09	49.81	49.67	48.03	
CoCR-OT	0.337	46.79	45.06	45.9	44.77	
CoSL-FM	0.647	49.67	50.4	48.69	49.25	
CoSL-OT	0.515	40.11	38.05	40.09	40.00	
CoSR-FM	0.472	48.96	49.56	49.80	48.01	
CoSR-OT	0.406	41.25	39.57	40.46	39.47	
JL-FM	0.258	32.41	33.43	31.94	31.77	
JL-OT	0.575	62.71	62.79	62.86	64.19	
JR-FM	0.267	32.46	34.36	32.51	31.90	
JR-OT	0.696	63.07	63.06	62.95	64.22	
MaL-FM	0.968	61.77	60.51	61.61	61.41	
MaL-OT	0.873	53.82	52.64	54.92	53.27	
MaR-FM	0.663	61.87	60.22	60.84	60.87	
MaR-OT	0.857	55.97	55.73	55.41	56.12	
MolL-FM	0.093	28.58	28.70	28.44	27.30	I and II from IV
MolL-OT	0.441	79.32	78.08	78.66	80.74	II from IV
MolR-FM	0.068	28.12	29.10	29.19	27.86	
MolR-OT	0.910	79.62	79.05	79.12	80.10	
ZyL-FM	0.978	63.49	63.91	63.83	63.55	
ZyL-OT	0.641	37.56	36.58	36.02	37.02	
ZyR-FM	0.846	62.40	63.04	63.03	62.16	
ZyR-OT	0.766	37.85	36.84	37.00	37.37	
Ramus R	0.360	61.02	60.10	61.82	58.73	
Ramus L	0.437	61.96	62.55	61.40	59.82	

*p-value <0.05

Table 2.10. Comparison of Cluster groups I, II, III and IV for All Craniofacial Dimensions Derived from Bilateral Horizontal and Vertical Measurements. One-way ANOVA Results for Males.

Measurement	F prob.	I	II	III	IV	Category difference
AgL-FM	0.329	42.40	42.73	45.23	42.35	
AgL-OT	0.266	103.34	105.67	109.46	107.37	
AgR-FM	0.415	42.41	43.43	44.51	45.05	
AgR-OT	0.835	101.79	102.87	106.22	105.39	
CoCL-FM	0.453	50.29	51.19	52.77	51.01	
CoCL-OT	0.740	46.92	47.67	47.13	50.44	
CoCR-FM	0.563	50.50	51.04	52.50	52.00	
CoCR-OT	0.470	47.01	46.37	43.57	49.83	
CoSL-FM	0.410	50.31	51.37	52.76	51.02	
CoSL-OT	0.444	40.05	42.09	41.39	44.89	
CoSR-FM	0.527	50.44	50.79	52.51	52.00	
CoSR-OT	0.790	41.48	41.07	40.08	44.37	
JL-FM	0.122	32.86	33.68	35.24	33.61	II from I
JL-OT	0.402	63.62	65.99	66.23	65.24	
JR-FM	0.710	32.93	33.79	33.88	33.65	
JR-OT	0.421	63.87	66.34	65.70	63.81	
MaL-FM	0.043*	56.39	57.48	60.12	59.85	III from I
MaL-OT	0.664	62.61	63.64	66.58	65.97	
MaR-FM	0.505	55.71	55.80	56.41	59.36	
MaR-OT	0.997	62.15	62.30	61.44	62.51	
MolL-FM	0.467	29.18	28.99	30.96	29.35	
MolL-OT	0.137	79.69	84.21	83.32	81.98	II from I
MolR-FM	0.563	29.34	29.40	31.11	29.79	
MolR-OT	0.607	79.90	83.03	80.65	80.81	
ZyL-FM	0.055	64.16	65.22	68.54	66.96	III from I
ZyL-OT	0.618	37.43	38.67	39.24	36.45	
ZyR-FM	0.321	63.93	64.83	66.79	66.00	
ZyR-OT	0.639	37.34	38.03	36.70	34.34	
Ramus R	0.180	62.21	62.51	69.06	61.61	III from I
Ramus L	0.532	62.99	64.21	67.53	63.24	

*p-value <0.05

References

1. Boering G. Arthrosis deformans van het kaakgewricht. Stafley en Tholen, Leiden, 1966
2. Ricketts RM. Clinical implications of the temporomandibular joint. Am J Ortho 1966;52(6):416-39
3. Moyers, Occlusion and TMJ disorders, in Developmental Aspects of Temporomandibular Joint Disorders, Center of Human Growth and Development, The University of Michigan, 1985
4. Stringert HG, Worms FW. Variations in skeletal and dental patterns in patients with structural and functional alterations of the temporomandibular joint: A preliminary report. Am J Ortho 89:285-297,1986.
5. Brand JW, Nielson KJ, Tallents RH, Nanda RS, Currier GF, Owen WL. Lateral cephalometric analysis of skeletal patterns in patients with and without internal derangement of the temporomandibular joint. Am J Orthod Dentofac Orthop 1995;107:121-8.
6. Dibbets JMH, van der Weele Lth. Signs and symptoms of TMD and craniofacial form. Am J Orthod Dentofac Orthop 1996;110(1)73-8.
7. Dibbets, JMH. Juvenile TMJ Joint Dysfunction and Craniofacial Growth: A statistical Analysis. Stafley and Tholen, Leiden, 1977.
8. Dibbets, JMH. Van der Weele LT, Uildriks AKJ. Symptoms of TMJ dysfunction: Indicators of growth patterns? The J of Pedodontics 1985;9:265-84;
9. Nebbe B, Major PW, Prasad NGN, Grace M, Kamelchuk LS. TMJ internal derangement and adolescent craniofacial morphology: A Pilot study. Angle Orthod 1997;67:407-14.
10. Shellhas KP, Piper MA, Omlie MR. Facial Skeleton Remodelling Due to Temporomandibular joint Degeneration: An Imaging Study of 100 Patients. AJNR 11:541-551. May/ June 1990; AJR 155: August 1990.
11. Shellhas KP, Piper MA, Bessette RW, Wylkes CH. Mandibular Retrusion,

Temporomadibular Joint Derangement, and Orthognathic surgery planning. Plastic and Reconstr Surg 90(2):218-229; 1990.

12. Link JJ, Nickerson JW. Temporomandibular joint internal derangements in an orthognathic surgery population. Int J Adult Orthod Orthognath Surg 1992;7:161-9.
13. Shellhas KP, Pollei SR, Wilkes GH. Pediatric internal derangements of the temporomandibular joint: Effect on facial development. Am J Orthod Dentofac Orthop 1992;101:79-83.
14. Mintz SS. Craniomandibular dysfunction in Children and Adolescents: A review. J of Craniomand Practice. 1993;Vol 11 (3): 224-231.
15. Keeling SD, McGorray S, Wheeler TT, King JK. Risk Factors associated with temporomandibular joint sounds in children 6 to 12 years of age. Am J Orthod Dentofac Orthop. 1994;105:279-87.
16. Dibbets JMH, Carlson DS. Implications of Temporomandibular Disorders for Facial Growth and Orthodontic Treatment. Semin Orthod 1995;1:258-272.
17. Nickerson JW, Boering G. Natural Course of Osteoarthrosis as it relates to Internal derangement of the Temporomandibular Joint. Oral Maxillofac Clinics North Amer. 1989;1(1):27-45.
18. Hans MG, Lieberman J, Goldberg J, Rosencweig G et al. A comparison of clinical examination, history, and magnetic resonance imaging for identifying orthodontic patients with temporomandibular joint disorders. Am J Orthod Dentofac Orthop. 1992;101:54-9.
19. Tasaki MM, Westesson PL. Temporomandibular joint: diagnostic accuracy with sagittal and coronal MR imaging. Radiology 1993;186:723-9.
20. Westesson PL, Katzberg RW, Tallents RH, Sanchez-Woodworth RE et al. CT and MR of the temporomandibular joint: comparison with autopsy specimens. Am J Roentgenol 1987;148:1165-71.
21. Westesson PL, Katzberg RW, Tallents RH, Sanchez-Woodworth RE et al. Temporomandibular joint: comparison of MR images with cryosectional anatomy.

Radiology 1987;164:59-64.

22. Westesson PL. Reliability and validity of imaging diagnosis of temporomandibular joint disorder. Adv Dent Res 1993;7:137-51.
23. Cirbus MT, Smilack MS, Beltran J, Simon DC. Magnetic resonance imaging in confirming internal derangement of the temporomandibular joint. J Prosth Dent 1987;57:488-94.
24. Major PW, Johnson DE, Hesse KL, Glover KE. Landmark identification error in posterior anterior cephalometrics. Angle Orthod 1994;64:447-54.
25. Nebbe B, Prasad NGN, Hatcher D, Major PW. Quantitative assessment of the temporomandibular joint disc status. Oral Surg Oral Med Oral Path Oral Radiol Endod (accepted for publication August 1997)
26. MacLennan R. Interrater Reliability with SPSS for Windows 5.0. The American Statistician 1993;47:292-6.
27. Dahlberg G Ed. Statistical methods for medical and biological students. London: G Allen& Unwin Ltd, 1940.
28. Fisher LD, Van Belle G. Biostatistics: a methodology for the health sciences. A Wiley-Interscience Publication, John Wiley and Sons, Inc New York, 1993;531-4.
29. Tasaki MM, Westesson PL, Isberg AM, Ren YF, Tallents RH. Classification and prevalence of temporomandibular joint disk displacement in patients and symptom-free volunteers. Am J Orthod Dentofac Orthop 1996;109:249-62.
30. Tallents RH, Katzberg RW, Murphy W, Proskin H. Magnetic resonance imaging findings in asymptomatic volunteers and symptomatic patients with temporomandibular disorders. J Prosthet Dent 1996;75:529-33.
31. Katzberg RW, Westesson PL, Tallents RH, Drake CM. Anatomic Disorders of the Temporomandibular Joint Disc in Asymptomatic Subjects. J Oral Maxillofac Surg 1996;54:147-153.
32. Drace JE, Enzmann DR. Defining the normal Temporomandibular Joint: Closed-, Partially Open-, and Open-mouth MR Imaging of Asymptomatic Subjects. Radiology

1990;177:67-71.

33. Kaplan PA, Tu HK, Williams SM, Lydiatt DD. The normal Temporomandibular Joint: MR and Arthtrographic Correlation. Radiology 1987;165:177-8.
34. Dibbets JMH, McNamara JA, Van Der Weele LT, Janosky JE. Multiple Linear Regression as an Analytical Tool in Cephalometric Studies. Brit J Orthod,24:61-6;1997.
35. Nebbe B, Major PW, Prasad NGN. Female Adolescent facial pattern associated with TMJ disc displacement and reduced disc length. Submitted for publication. In Nebbe B. Adolescent Facial Morphology and TMJ Internal Derangement. 1998; Doctoral Thesis. University of Alberta.
36. Heikinheimo K, Salmi K, Myllerniemi S, Kirveskari P. A longitudinal study of occlusal interferences and signs of craniomandibular disorder at the ages 12 and 15 years. Europe J Ortho. 1990;12:190-197.
37. Wanman A, Agerberg G. Two-year longitudinal study of symptoms of mandibular dysfunction in adolescents. Acta Odontol Scand. 1986;44:321-31.
38. Gazit E, Lieberman M, Eini R, Hirsch N et al. Prevalence of mandibular dysfunction in 10-18 year old Israeli schoolchildren. J Oral Rehab. 1984;11:307-17.
39. Egermark-Eriksson I, Carlsson GE, Ingervall B. Prevalence of mandibular dysfunction and orofacial parafunction in 7-, 11- and 15-year -old Swedish children. Europ J Ortho. 1981;3:163-72.
40. Solberg WK, Woo MW, Houston JB. Prevalence of mandibular dysfunction in young adults. JADA. 1979;98:25-34.
41. Mc Namara JA. Functional determinants of craniofacial size and shape. Eur J Orthod 1980;2:131-159.

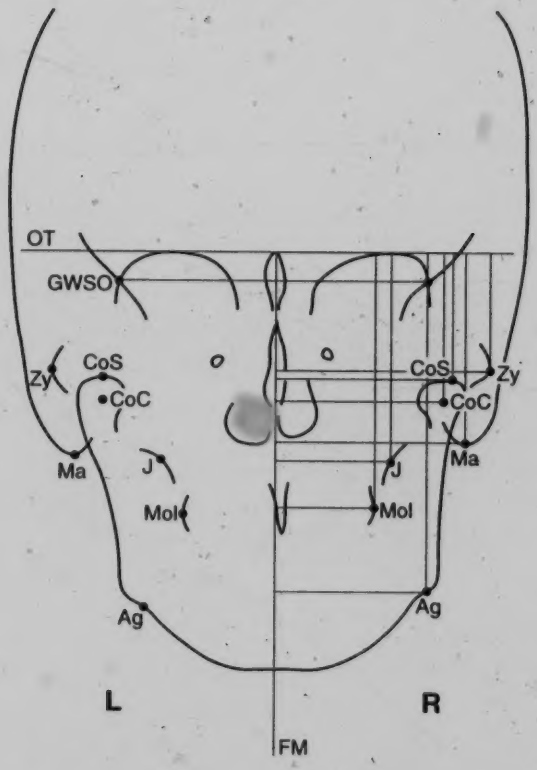

FIGURE 2.1 Cephalometric Landmarks and Reference Lines

FIGURE 2.2 Establishment of Plane for Quantitive MRI Assessment

FH -Frankfort Horizontal

ERP-Eminence Reference Plane

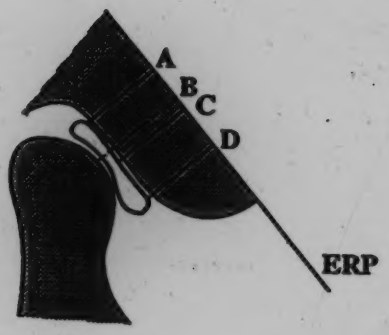

FIGURE 2.3 Reference Points for Determining Disc Lenght and Disc Displacement

A- posterior band; B-condylar load point;

C-midpoint of the disc; D-anterior band

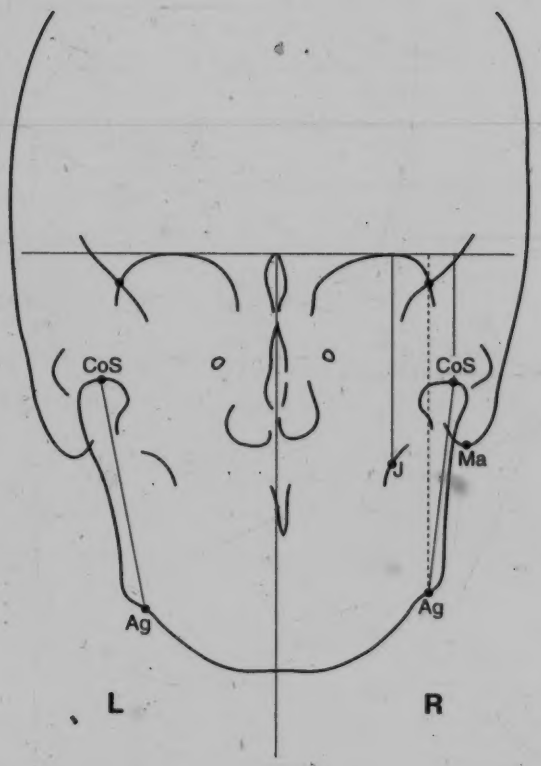

FIGURE 2.4 Cephalometric Variables Associated with TMJ ID. Females

Full Line Signifies Variables Entered in the Multiple Linear Regression Equation; Dashed Line Signifies Variable Significantly Different in the ANOVA Outcome.

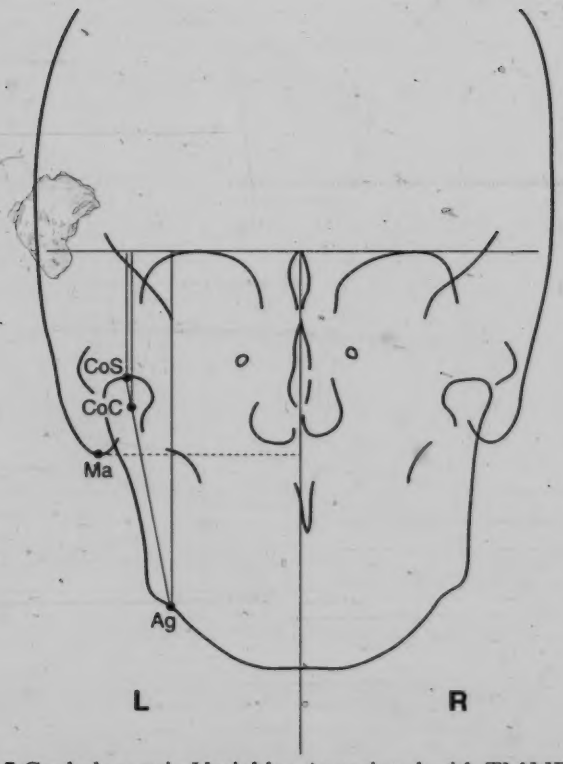

FIGURE 2.5 Cephalometric Variables Associated with TMJ ID. Males

Full Line Signifies Variables Entered in the Multiple Linear Regression Equation; Dashed Line Signifies Variable Significantly Different in the ANOVA Outcome

CHAPTER III

SECOND RESEARCH STUDY AND RESULTS

CRANIOFACIAL ASYMMETRY ASSOCIATED WITH TMJ INTERNAL DERANGEMENT IN ADOLESCENTS: A POSTERIOR-ANTERIOR CEPHALOMETRIC STUDY

3.1 INTRODUCTION

The goal of orthodontic treatment of patients is harmonious facial appearance. One aspect of this harmony is craniofacial symmetry. By definition, symmetry indicates equality in form and size of parts distributed around a center of an axis, at two extremes or poles, or on the opposite sides of the body. However, this concept of symmetry is applicable to the *living* being only to a limited extent. In humans, as in all mammals, a right-left asymmetry in the distribution, size, and form of the visceral organs exists. This has developed to accommodate various functional requirements.[1] Humans exhibit not only anatomical but also functional departures from ideal symmetry. For instance, behavioural asymmetry is well illustrated by handedness. About 90% of the population are right handed while only 10% are left handed. Preference for using one eye or one leg for performing specific activities is also evident.[2]

Based on the degree of craniofacial asymmetry, the following three categories have been differentiated:[3]

- minor asymmetry
- moderate asymmetry
- severe asymmetry

Minor asymmetry is a common finding and represents a normal variation in size, shape, or form between the two halves of the skeletal components. A minor degree of

asymmetry is not only trivial but also a desirable variation of the craniofacial structures, as we perceive these minor inconsistencies as aesthetically pleasing. Zaidel et al. [4] ascribed a critical role to asymmetry in facial attractiveness; the right side of females has been consistently judged as more attractive than the left side. Peck et al. found asymmetry in fifty-two individuals with well-balanced faces, including professional models, beauty contest winners, and performing stars. [5]

Although facial asymmetry exists in individuals with normal facial appearance [1, 6-14] there is no consensus about its degree, side or localization. Larger left side has been found in several reports, [6-9] but other authors have reported larger right side. [5, 10-12] Asymmetry of the craniofacial complex may be greater in childhood and adolescence due to relative growth imbalances between the right and left sides. [13] Cross sectional studies completed at the University of Toronto in the 1960s indicated a left side mandibular dominance before the age of 9 years. Mandibular asymmetry fluctuates in magnitude and side prevalence with increasing age.[13,15]

Facial asymmetry in children and adolescents might be related to gender.[11] In boys, relative maximum side differences decrease whereas in girls increase with age. Generally, more boys than girls show asymmetries. In adult population no gender-associated differences of craniofacial asymmetry have been reported. [9, 12]

Mild asymmetry of the craniofacial complex exists in every individual. Anthropometric study of healthy children did not demonstrate systematic asymmetry since the correlation between asymmetry of different craniofacial regions was low. [11] This balance of side differences in normal subjects creates the inconspicuous nature of physiological asymmetries.

Numerous etiologic factors produce severe craniofacial asymmetries. Cohen in a series

of six articles published in 1995 [2,16-20] reviewed the common and well-known etiologic factors of gross craniofacial asymmetries.

Moderate asymmetry occupies the spectrum between mild and severe asymmetry. The degree of craniofacial asymmetry which exceeds the functional and visual harmony is a measure of important clinical significance. The orthodontist generally uses visual analysis to determine the patient's facial balance. [21] Additional evaluation is considered if the asymmetry appears clinically significant. Most often, the cause of mild to moderate mandibular asymmetry is not obvious at clinical examination.

Both genetic and environmental factors control the growth rate difference between the right and left side.[1] Mulick [14] using the serial twin-study method could not prove a strong genetic influence on craniofacial asymmetry and concluded that external unfavourable factors can exert significant influence on the final craniofacial asymmetry.

Degenerative temporomandibular joint (TMJ) disease may be an important etiologic factor in mandibular growth disturbances such as mandibular deficiency and open bite. [22, 23] Boering [22] and Ricketts [23] independently in 1966 recognised the presence of juvenile degenerative TMJ disease, and emphasized its importance in the development of disturbed mandibular growth. Mandibular retrusion and occlusal instability as well as vertical facial asymmetry or chin deviation to the affected side are other clinical signs associated with TMJ pathology. [24]

The term temporomandibular joint disorder (TMD) describes conditions characterized by pain in the preauricular area, the TMJ or the muscles of mastication, limitation of mouth opening and presence of joint sounds during jaw function. Epidemiological surveys of TMJ dysfunction in children have found prevalence of clinical signs and

symptoms in 30 to 52% of the population. [25] TMJ noises and masticatory muscles tenderness are most frequent signs discovered during clinical examination. Although the prevalence of TMJ problems in children may be as high as in adults, the symptoms are mild and transient in nature and only a small percentage of patients will ever seek treatment. [26]

Internal derangement (ID) of the TMJ is a common structural intra-articular disorder, characterized by an abnormal relationship of the articular disc relative to the mandibular condyle, fossa and articular eminence. Disc displacement is synonymous with internal derangement and refers to any positional disc abnormality within the joint. Studies indicate that almost 80% of patients with TMD have a form of internal derangement. [27-30] TMJ internal derangement was revealed in 94% of pediatric TMD population. [31] Magnetic resonance imaging (MRI) discovered disc displacement in 5% [32] up to 11.8% [33] in non-symptomatic orthodontic juvenile population.

Juvenile TMD patients have smaller overall length of the mandible, shorter posterior facial height, shorter ramus and shorter corpus, larger gonial angle and steeper mandibular plane. [34,35] Until recently there has been no consideration in treatment planning that mandibular asymmetry can be related to long-standing TMJ internal derangement. [36] Several authors have suggested that TMJ internal derangement and degenerative joint disease could be the main causes for mild to moderate facial asymmetry due to mandibular growth deficit in a growing child or adolescent. [24, 37-39]

The degree to which TMJ disorder can effect facial growth depends on the time of onset and the duration of the condition. [40] It is also important to consider the severity of the disorder and whether it is a unilateral or bilateral condition. [34]

The objective of this cross sectional study was to explore whether TMJ internal

derangement associated with a greater degree of craniofacial asymmetry in a sample of growing patients. The hypothesis was that a TMJ ID can potentially retard the ipsilateral growth of the mandible.

3.2 MATERIALS AND METHODS

3.2.1 Sample

A study on craniofacial growth disturbances associated with TMJ internal derangement was initiated at the TMJ Investigation Unit , University of Alberta. The subjects included were Caucasian, between the ages 10 to 17 years and without any history of previous trauma, infection, tumours, rheumatologic disease or other clinically significant pathology affecting the craniofacial region. All subjects were unselected in regard to dental occlusion. Patients suspected to have a TMJ ID (according to subjective complaints and clinical evaluation) were referred to the TMJ Clinic by practicing Orthodontists in Edmonton. The remainder of the sample group was obtained from adolescents presenting consecutively for Orthodontic treatment in a private Orthodontic Practice as well as the Graduate Orthodontic Clinic at the University of Alberta. Each patient received bilateral temporomandibular joint magnetic resonance imaging, obtained at the Magnetic Resonance Centre of Edmonton, using 1.0 Tesla machine (Shimadzu Corporation 3, Kanda-Nishikicho 1-chrome, Chiyoda-Ku, Tokyo, Japan). Bilateral closed mouth sagittal sections perpendicular to the condylar long axis were obtained with a unilateral 3-inch surface receiver coil. T1-weighted 500/20 (TR ms/TE ms) pulse sequences were performed, using a 3 mm slice thickness, 140 mm field of view, NEX of 2, and an image matrix of 204x204. Mandibular position in centric occlusion was secured with polyvinylsiloxane bite registration (President Jet-Bite, Coltane/Whaledent Inc., Mahwah, New Jersey).

Posterior-anterior cephalograms were obtained at Edmonton Diagnostic Imaging , using a Siemens OP10 x-ray machine with standardised exposure, source to ear rod distance of 60 inches and ear rod to film distance of 5 inches. Head positioning was maintained with Frankfort horizontal parallel to the floor. Mandibular position was

reproduced using the same centric occlusion bite registration used during the MR imaging.

The records of one hundred and thirty-seven preorthodontic patients, eighty females (mean age 13.20 years, SD 1.70, range 10.01 to 16.64 years) and fifty-seven males (mean 13.26 years, SD 1.84, range 9.57 to 17.09 years) were available for this study.

3.2.2 Cephalometric Analysis

Posterior-anterior cephalograms were used to measure craniofacial asymmetry in vertical and transverse dimension. All radiographs were traced twice by one observer on a transparent acetate paper with a 0.3mm 3H pencil. The choice of landmarks was based on previously published PA cephalometric reproducibility studies. [41] Landmark registration was performed manually. Six bilateral skeletal, one dental bilateral, two skeletal midline and two dental midline points were identified. Orbita tangent (OT) was drawn to represent the horizontal reference line. Vertical reference line, i.e., Facial midline (FM) was constructed as a line passing through the midpoint of a line drawn between the intersections of the greater wing of the sphenoid bone and the orbital margin (GWSO), perpendicular to the OT (Figure3.1). Deviations from the midline were also measured as the perpendicular distance from the midpoints of the facial skeleton to the estimated facial midline. The landmarks and reference lines used are listed and defined in Table 3.1.

Asymmetry Analysis

A total of seven paired horizontal and seven paired vertical variables as well as ramus height on left and right side were obtained of each tracing. The right and left side differences between measurements were expressed in millimetres. Asymmetry for each

measurement was calculated according to the formula (R-L)/ (R+L)x200.

Midline landmark deviations from the facial midline provided four asymmetry variables, which were assigned a positive value if skewed to the right, and a negative value if skewed to the left.

A total of nineteen asymmetry variables per patient was collected.

3.2.3 MRI Analysis

Quantitative measures of disc displacement and disc length values were obtained from sagittal MRI slices using the procedure described by Nebbe et al. [42] On each MRI slice tracing a reference plane was drawn as a line intersecting the patient's transferred Frankfort horizontal at 50- degree angle through a point 10 mm anterior to the maximum height of the articular fossa. (Figure 3.2) The condylar load point (CLP) was determined as the shortest distance between the condyle and the articular eminence along a line perpendicular to the reference line. Three landmarks were identified on the contours of the articular disc: anterior band, posterior band and midpoint of the disc(Figure 3.3). From each landmark perpendicular lines were erected to the constructed reference line. Disc displacement was measured as the distance from the midpoint of the disc to the CLP along the reference line. Negative values for disc displacement implied that the midpoint of the disc was posterior to the condylar loading point and represented a variation of normal disc position. Disc length was measured as the distance from the anterior to the posterior band of the disc along the reference line. Based on previous findings of a negative correlation between disc displacement and disc length [42] it was decided to produce a positive correlation between these two scores by subtracting measurements of disc length from an averaged normal value for disc length of 10 mm. The values obtained ranged from negative values, representing disc

length greater than 10 mm and therefore normal, to positive values describing disc shortening of increasing severity. In this way several variables measuring disc displacement and disc length were obtained per joint. Instead of averaging these values for each joint, principal components analysis (SPSS for Windows, SPSS Inc. Chicago, IL) was used to integrate the measurements of each slice into a single weighted score for disc displacement and score for disc length for each joint. The same statistical procedure was used to synthesise disc displacement and disc length scores into one total score for TMJ ID (TMJ ID-Left; TMJ ID -Right).

3.2.4 Method Error

Intra-observer reproducibility-Cephalometry

Ten PA cephalograms were randomly selected, coded, and traced five times by the principal observer under the same conditions, with a minimum of one week time between tracings. Intra-observer reproducibility was expressed as coefficients of reliability, which represent the internal consistency, i.e., within patient homogeneity of measurements obtained from five replicated tracings. [43] The closer the value of the coefficient to 1, the greater the reliability of the observer. All linear paired measurements and midline measurements had coefficients of reliability ranging from 0.8798 to 0.9988, which can be considered insignificant method error due to intraobserver reproducibility of tracings.

Intra-observer reproducibility- MRI

Ten MRI-s representing normal disc position and ten MRI-s representing internal derangement were selected and randomly traced five times on consecutive days. Multivariate ANOVA procedure with MRI tracings as factors produced F-statistic and a coefficient of intra-rater reliability R (Rel=1-1/F). Disc length and disc displacement

coefficients of reliability were excellent, at 1.00 to 0.98 respectively.

Measurement error

Two tracings of each cephalogram were obtained and measured with a minimum of one week interval. Dahlberg's formula [44] for repeated measures was used to calculate the mean, standard deviation and range of standard error for paired and midline measurements. Error associated with paired asymmetry variables was calculated using values for standard error of each measurement for the right and left side and the value of the correlation coefficients between these measurements.

3.2.5 Statistical Methods

1. Patient classification into groups based on TMJ ID scores was accomplished using cluster analyses. Two analyses were performed:

a. To group the patient population into four categories according to TMJ ID score severity and location (unilateral or bilateral) using:

- TMJ ID R minus TMJ ID L (R-L) -- side difference between TMJ ID within patient (measure of TMJ ID asymmetry)
- TMJ ID R plus TMJ ID L (R+L) -- sum of bilateral TMJ ID scores within patient (measure of severity of TMJ internal derangement)

In this way four categories of patients were produced:

I. Patients with close to zero R-L and close to zero R+L; these comprised the group of bilaterally normal TMJ-s.

II. Patients with positive R-L score and positive R+L score, representing patients with right unilateral TMJ ID.

III. Patients with negative R-L and positive R+L score, representing patients with left unilateral TMJ ID.

IV. Patients with R-L score close to zero and positive R+L score, describing bilaterally abnormal TMJ-s of approximately equal severity.

Groups II and III were combined into one category of unilateral TMJ internal derangement.

b. To group the patient population into three categories for TMJ ID side dominance, determined as the difference between the right and the left TMJ score. The categories obtained were the following:

IV. No difference in TMJ status between the right and left side. This category included patients with bilaterally normal TMJ -s and patients with bilateral TMJ ID of equal severity

V. Positive R-L score. Patients with unilateral TMJ ID on the right side as well as patients with bilateral TMJ ID of greater severity on the right side.

VI. Negative R-L score. Patients with unilateral TMJ ID on the left side as well as patients with bilateral TMJ ID of greater severity on the left side.

2. The mean values of normal asymmetry for each measurement were calculated within the patient group free of TMJ ID. The mean values obtained were then subtracted from the respective mean values for the entire patient population. The differences were added to each patient's corresponding reading for each craniofacial asymmetry measurement. In this way, all variables to be tested were adjusted for normal asymmetry.

3. One way ANOVA statistics were used to test whether the mean values of craniofacial asymmetry measures between cluster categories were significantly different.

4. Multiple linear regression was used for analysing the relationship between all craniofacial asymmetry variables as independent and TMJ ID scores as dependent variables. The influence of age upon craniofacial asymmetry and TMJ ID scores was tested and factored out prior to further regression analyses. Age represented

independent while craniofacial asymmetry and TMJ ID scores were dependent variables for multiple regression statistics. However, multiple linear regression is a statistical model in which the rate of change between analysed variables should conform to linear relationship while in reality the relationship between age and craniofacial dimensions is non-linear. Polynomial regression techniques were used to overcome this inconsistency.[45] Multiple regression equations were fitted with age and its quadratic values age squared and age cubed as independent variables for each asymmetry measurement and TMJ ID score. If found significant, variability due to age or its quadratics was eliminated by mathematical transformation. The sum of B-constant value (y-intercept) and the portion of the tested variable that was unexplained by age (residue) were used to produce new variables for craniofacial asymmetry or TMJ ID scores which were used for further multiple linear regression tests.

5. Multiple linear regression analysis was used to study the relationship between the following variables:

a. Right side TMJ ID score and absolute values of craniofacial asymmetry measurements

b. Left side TMJ ID score and absolute values of craniofacial asymmetry measurements

c. TMJ ID R minus TMJ ID L (R-L) and signed craniofacial asymmetry measurements, testing the direction as well as amount of asymmetry

d. TMJ ID R plus TMJ ID L (R+L) and absolute craniofacial asymmetry measurements (severity of bilateral TMJ ID and severity of asymmetry)

Statistical significance level for all analyses was set at $p<.05$.

3.3 RESULTS

Random error results are listed in Table 3.2 for midline measurements and Table 3.3 for paired asymmetry measurements. For the purposes of this study 1% for paired asymmetry measures and 1 mm for midline asymmetry measures were considered acceptable margin of error. Errors of most paired asymmetry and all four midline measures did not exceed the acceptable limit. Variables having more than 1% measurement error should be considered with caution.

A slight left side dominance was noticeable in the "normal" population, i.e., in the portion of our sample free of TMJ ID. (Table 3.4). For females the most asymmetric variables were MaH% (-4.16%) and Me-FM (1.12 mm), while for males, CoSV% at 3.73% and Me-FM at 1.00 mm were most asymmetric structures.

Classifications of patients according to cluster analyses are listed in Tables 3.5 and 3.6. Forty-seven percent of female patients had some form of TMJ ID. Twenty-nine percent had unilateral TMJ ID (16% involving the right TMJ, and 13% involving the left TMJ), while 19 % had a bilateral TMJ ID. In the male sample, only two patients had bilateral TMJ ID. In 22% of our male patients there was a TMJ ID detected, which was slightly more prevalent on the right side (12%). These numbers were further reduced in the second cluster analysis (Table 3.6). Based on these findings it was decided to proceed with subsequent analyses for girls only, since no reliable conclusions could have been drawn with such small numbers of male patients in different cluster categories. Tables 3.7 and 3.8 contain the one-way ANOVA outcome when means of craniofacial asymmetry measures were compared between the female cluster groups.

The results obtained with multiple linear regression are presented in Table 3.9 . The purpose of this analysis was to determine which of the craniofacial asymmetry

measurements are significantly associated with TMJ ID, and as such can be used in explaining the variability observed in joint status. These are listed under the independent variable column.

3.4 DISCUSSION

The sample analysed in this study was selected in an attempt to have a spectrum of TMJ disc status ranging from normal to disc displacement with deformation. The prevalence of ID identified in this study cannot be applied to the general adolescent preorthodontic population.

The results of this study are not directly comparable to previous investigations. The only other work to assess the relation between TMD and facial symmetry was the work of Dibbets. [34] He considered patient complaints and clinical signs to assess joint status, as well as transcranial radiography to identify Arthrosis Deformans Juvenilis. This study used objective MRI measurements to characterise TMJ articular disc status (internal derangement). The accuracy of MRI in diagnosing internal derangement ranges from 73% up to 90% or higher.[46,47] Lieberman et al. [32] found a discrepancy of 54% between clinically diagnosed (59%) and MRI verified (5%) presence of internal derangement in random preorthodontic sample. Imaging studies on asymptomatic subjects with clinically normal TMJ-s have revealed a disc displacement in 11.8% in orthodontic juvenile patients, [33] and 15% in adult patients.[48,49] Subjective assessment has been most frequently used in MRI diagnostics. [47] This study utilized an objective analysis for measuring internal derangement from MRI slices. [42] With this method, error due to overestimation or underestimation of internal derangement severity is avoided. Osseous morphology was not assessed in this study.

Overall, a slight left side predominance was noticeable in the portion of our sample free of TMJ ID. Normal asymmetry measurements showed large standard deviations which suggests a larger sample size might be required to establish a reliable population asymmetry mean. The pre-existing "normal" asymmetry can mask or inflate the presumed reduction or lack of condylar growth in the TMJ. For instance in a patient

with left unilateral TMJ ID, or a bilateral TMJ ID that has started on the left side, a pre-existing left dominant asymmetry will be neutralised by the reduced left side growth, and therefore may not be detected as an increase in asymmetry. The opposite situation, a right unilateral or bilateral TMJ ID that has started on the right side and a pre-existing left dominant asymmetry will result in even more pronounced left side dominance as the right side lags in growth.

The ANOVA results (Tables 3.7 and 3.8) revealed that for most craniofacial regions the amount of asymmetry did not differ significantly between female adolescents with normal TMJ-s and patients with either unilateral or bilateral TMJ ID. These findings were expected for upper and middle craniofacial structures. The deviation of the anterior nasal spine from the facial midline (ANS-FM) in patients with unilateral TMJ ID represents a difference of 0.6 mm in magnitude which is clinically not significant. According to our working hypothesis that TMJ ID could impair mandibular growth, lower facial regions were expected to show differences especially between patients with unilateral TMJ ID versus bilateral TMJ ID or bilaterally normal TMJ-s. The amount of vertical asymmetry in the region of mandibular antegonion was significantly different between the first three cluster categories. However, contrary to the expected, a greater amount of asymmetry was found in patients with bilateral TMJ ID (4.969%) as compared to females with bilaterally normal TMJ-s (2.367%), whereas females with unilateral TMJ ID did not differ significantly from the other two groups (3.5975). It appeared that there was a progression of asymmetry from group I to group III, with group II being intermediate. Time difference in the onset of TMJ ID, on one side first and then on the other, in patients with bilateral TMJ ID could explain this finding. We could merely verify the soft tissue joint changes in one point of time, and we had no knowledge about the exact time of onset and the duration of these changes within the TMJ-s. Bilateral TMJ ID disorder likely develops over a longer time period than unilateral TMJ ID; therefore, its influence upon facial growth can be greater. In children

and adolescents with juvenile rheumatoid arthritis (JRA) reduced ramus and total face height consistently support the idea of mandibular growth failure. [50-52] Greater variance of ramus height asymmetry and overall mandibular length asymmetry has been demonstrated in JRA patients as compared with healthy children while transverse mandibular dimensions were similar with controls. [52,53] In adult patients with JRA mandibular asymmetry is infrequent. [54] These studies imply that the time period between 7 and 17 years may be a transitional stage from unilateral to bilateral growth retardation. Similar concept could apply to internal derangement of the TMJ-s. Available literature suggests that mild to moderate asymmetry of unknown aetiology tends to improve with growth. [13,15] A longitudinal investigation is required to comprehend the craniofacial development of patients with unilateral or bilateral TMJ ID.

Cluster groups IV, V and VI allowed us to compare both the magnitude and the direction of asymmetry in relation with TMJ ID asymmetry. The one measurement significantly different for Cluster groups IV, V and VI in the female group was ramus height discrepancy (Table 3.8). In this instance, patients with TMJ ID dominant on the right side had shorter right ramus as expressed with the negative mean value of ramus index % (-2.452) in comparison with dominant left ID (0.2148%) and patients with similar left and right joint disc status (-0.6536%). Although the direction confirms the expected trend, the magnitude of difference does not appear to be clinically significant, since it is only 1.79%.

In our female sample there was a slight left dominant normal asymmetry. This could explain why in cluster group V (unilateral right TMJ ID) ramus height was more asymmetric while cluster group VI (unilateral left TMJ ID) did not differ significantly neither in amount nor in direction of asymmetry (Table 3.8).

We used multiple linear regression analysis to evaluate which regions of the craniofacial skeleton exhibit asymmetry that may explain the variability of TMJ ID. The results of the multiple regression analysis (Table 3.9) show that the highest R^2 value was obtained for the R-L variable (0.20). This means that asymmetry of ramus height and the deviation of ANS and Inl explained 20 % of the difference in TMJ ID severity between the right and the left side. The low R^2 value for R+L in females (4%) could mean that the sum of structural change within both TMJ-s was not associated with greater amount of asymmetry. R+L is a measure that contains both unilateral and bilateral TMJ ID cases. The discrepancy between these two R^2 values suggests that asymmetry of the craniofacial structures is associated with TMJ ID asymmetry, regardless of the severity of TMJ change.

Overall vertical asymmetry showed statistically significant difference with regard to TMJ ID as opposed to transverse asymmetry. This is consistent with previous lateral cephalometric studies that have shown reduced vertical posterior facial and ramus height in adolescent TMD patients [34] and in adult patients. [55]

This was a cross sectional investigation, and the time of onset of TMJ ID could not be considered. Duration of a TMJ ID can only be studied in a longitudinal design of study. These patients with TMJ ID should be reevaluated at a different point in time and their continued growth should be monitored. The rate of change in TMJ ID severity should be compared with the rate of change in craniofacial asymmetry. The amount of asymmetry that was statistically significant between patients in different cluster groups did not appear to be of a magnitude that is clinically important. Future research is required to clarify the association of TMJ ID and craniofacial asymmetry.

3.5 SUMMARY AND CONCLUSIONS

Females with bilateral TMJ ID are more likely to have vertical mandibular asymmetry in comparison with females with unilateral TMJ ID or females with normal TMJ-s. The amount of craniofacial asymmetry as demonstrated in this investigation may not be clinically significant.

Table 3.1. Cephalometric Landmarks, Reference Planes and Asymmetry Measurements

Bilateral Landmarks

Zy Zygomatic point- the most lateral aspect of the zygomatic arch

Ma Mastoid Point- the most inferior point on the mastoid process

CoS Condyle Superior- the most superior aspect of the mandibular condyle

CoC Condyle Center- the center of the mandibular condylar head

JP Jugal Point- the deepest point on the curve of the malar process of the maxilla

Ag Antegonion- the deepest point on the curvature of the antegonial notch

Mol Maxillary first Molar- the midpoint on the buccal surface of the maxillary first molar

Midline Landmarks

ANS Anterior Nasal Spine- the center of the intersection of the nasal septum and the palate

Me Menton- the midpoint on the inferior border of the mental protuberances

InS Incisor Superior- upper dental midline, the contact point between the maxillary central incisors

InI Incisor Inferior- lower dental midline, the contact point between the mandibular central incisors

Mandibular Ramus Height

Ramus R--the distance from the superiormost point on the outline of the right mandibular condyle to the ipsilateral antegonion CoSR-AgR

Ramus L--the distance from the superiormost point on the outline of the left mandibular condyle to the ipsilateral antegonion CoSL-AgL

Horizontal reference line

OT Orbita Tangent, the line connecting the uppermost points on the superior outline of the right and left orbits

Vertical reference line

FM Facial midline -The perpendicular to the orbita-tangent line drawn through the midpoint of the distance between the right and left GWSO

GWSO Greater Wing Superior Orbit - intersection of the superior border of the greater wing of the sphenoid bone and the orbital outline

Bilateral asymmetry variables

ZyH% --Zygomatic Horizontal -- width difference between the right and the left side

ZyV% --Zygomatic Vertical -- height difference between the right and the left side

CoSH% --Condyle Superior Horizontal -- width difference between the right and the left side

CoSV% --Condyle Superior Vertical -- height difference between the right and the left side

CoCH% --Condyle Center Horizontal -- width difference between the right and the left side

CoCV% --Condyle Center Vertical -- height difference between the right and the left side

MaH% --Mastoid Horizontal -- width difference between the right and the left side

MaV% --Mastoid Vertical -- height difference between the right and the left side

MolH% --First Molar Horizontal -- width difference between the right and the left side

MolV% --First molar Vertical -- height difference between the right and the left side

JH% --Jugal Horizontal -- maxillary width difference between the right and the left side

JV% --Jugal point Vertical -- maxillary height difference between the right and the left side

AgH% --Antegonion Horizontal -- mandibular width difference between the right and the left side

AgV% --Antegonion Vertical -- mandibular height difference between the right and the left side

Ramus%--Ramus height difference between the right and the left side

---

Table 3.2. Measurement Error as Estimated from Replicated Tracings for Midline Cephalometric Variables

Midline measurements	Standard error Mean SD (mm)	Standard error SD (mm)	Standard error Min SD (mm)	Standard error Max SD (mm)
ANS	0.31	0.31	.00	1.53
InI	0.30	0.30	.00	1.92
InS	0.33	0.31	.00	1.77
Me	0.72	0.65	.00	3.46

Table 3.3. Measurement Error of Bilateral Asymmetry Variables

Measure	mean right	sd right	mean left	sd left	correlation	SE (%)
AgH%	0.5	0.42	0.56	0.43	0.2022	0.535
AgV%	0.48	0.43	0.54	0.49	0.6805	0.385
CoCH%	0.58	0.59	0.58	0.6	0.5508	0.486
CoCV%	1	1.14	0.9	0.99	0.8283	0.319
CoSH%	0.71	0.74	0.66	0.66	0.5342	0.477
CoSV%	1	1.2	1.51	1.39	0.8149	0.387
JH%	0.58	0.61	0.64	1.36	0.4368	1.052
JV%	0.74	0.81	0.71	0.58	0.8795	0.275
MaH%	0.4	0.44	0.4	1.48	0.3623	1.728
MaV%	0.32	0.29	0.33	0.31	0.894	0.217
MolH%	0.38	0.4	0.45	0.64	0.1208	0.93
MolV%	0.49	0.65	0.49	0.5	0.9114	0.288
ZyH%	0.27	0.59	0.37	0.68	0.7211	0.869
ZyV%	0.48	0.41	0.71	1.86	0.6845	1.611
Ramus%	1.19	1.28	1.21	1.16	0.8848	0.25

Table 3.4. Range of Normal Asymmetry in Adolescents Free of TMJ ID.

(Negative Values Represent Left Side Dominance).

Variable	Females		Males	
	Mean (mm)	SD	Mean (mm)	SD
AgH%	-1.88	10.32	0.69	9.11
AgV%	-0.60	2.76	-2.22	11.31
CoCH%	-1.17	7.34	0.80	5.60
CoCV%	0.67	5.21	0.15	4.51
CoSH%	-1.52	7.52	0.64	5.45
CoSV%	-1.98	31.52	3.73	6.48
JH%	-0.08	9.71	-0.13	8.31
JV%	0.52	2.85	0.50	2.30
MaH%	-4.16	9.29	-0.79	7.23
MaV%	0.10	4.93	-0.83	4.03
MolH%	-1.80	8.34	0.72	10.57
MolV%	0.38	2.29	0.28	1.47
ZyH%	-1.66	4.64	-0.16	3.31
ZyV%	1.13	6.63	-0.39	5.41
Ramus%	-0.78	2.09	-0.53	1.57
ANS-FM	0.25	1.08	0.23	1.43
InS-FM	0.43	1.43	0.00	1.90
InI-Fm	0.22	1.68	0.08	2.33
Me-FM	1.12	3.16	1.00	2.72

Table 3.5. Cluster Groups Formed by Combining TMJ ID Data: Right TMJ ID Score minus Left TMJ ID score, and Right TMJ ID Score plus Left TMJ ID Score

		Cluster Center			Cluster Center		
Cluster group	Females	R-L	R+L	Males	R-L	R+L	Total
I.Bilateral Normal TMJ	42 (52.5%)	-0.124	-1.3414	44 (77.19%)	0.0396	-0.8135	77
II. Unilateral R TMJ ID*	13 (16.25%)	1.2534	0.5919	7 (12.2%)	1.4803	2.0380	33
II. Unilateral L TMJ ID*	10 (12.5%)	-1.5612	0.7210	4 (7.01%)	-2.8809	2.5836	22
III. Bilateral TMJ ID	15 (18.75%)	-0.631	2.9246	2 (3.5%)	0.5403	4.7660	15
Total	80			57			137

* Cluster groups TMJ-R and TMJ -L were combined into one group of unilateral internal derangement

Table 3.6. Cluster Groups Based on TMJ ID Data, Regarding TMJ ID Side Dominance. Variable Used was Right TMJ ID Score minus Left TMJ ID score.

	Females	Cluster Center	Males	Cluster Center	Total
IV. No side dominance	52 (65%)	-0.0391	50 (87.7%)	0.1045	102
V. Right dominant	16 (20%)	1.2815	3 (5.26%)	2.6536	19
VI. Left dominant	12 (15%)	-1.6046	4 (7.01%)	-2.8809	16
Total	80		57		137

Table 3.7. ANOVA Comparisons of Amount of Asymmetry (Absolute Values of Asymmetry Measurements) for Cluster Groups I, II and III . Females

Measurement	p-value	I (n=42)	II (n=23)	III (n=15)
ANS-FM. abs (mm)	0.009	0.770	1.320**	0.708
InS-FM abs (mm)	0.201	1.098	1.565	1.385
InI-FM abs (mm)	0.098	1.188	1.879	1.481
Me-FM abs (mm)	0.400	2.094	2.446	2.908
AgH%	0.305	5.640	6.492	8.398
AgV%	0.051*	2.367	3.594	4.968**
CoCH%. abs	0.774	4.032	3.701	3.301
CoCV%	0.733	3.531	4.174	4.079
CoSH%	0.539	4.122	3.984	2.947
CoSV%	0.973	5.061	5.360	5.209
MaH%	0.932	5.477	5.993	5.464
MaV%	0.678	3.119	3.513	3.943
MolH%	0.573	6.055	7.466	6.129
MolV%	0.941	1.182	1.240	1.328
JH%	0.562	4.355	5.745	4.704
JV%	0.391	1.768	1.518	2.317
ZyH%	0.584	2.752	2.346	3.213
ZyV%	0.667	4.116	4.698	4.671
Ramus%	0.906	1.5517	1.710	1.587

*p-values < 0.05

**Significantly different from the other two groups in the same row

Table 3.8. ANOVA Comparisons of Means of aAymmetry for Craniofacial Measurements Between Cluster Groups IV, V and VI. Females

Measurement	p-value	IV (n=52)	V (n=16)	VI (n=12)
ANS-FMabs (mm)	0.190	0.589	0.501	1.192
InS-FM abs (mm)	0.820	0.875	0.725	1.103
InI-FM abs (mm)	0.666	0.909	1.316	0.725
Me-FM abs (mm)	0.749	2.060	2.211	1.410
AgH%	0.931	1.963	2.889	1.617
AgV%	0.684	-3.386	-1.724	-1.600
CoCH%. abs	0.784	-0.153	-1.393	0.008
CoCV%	0.242	-1.554	1.033	-2.250
CoSH%	0.734	-0.564	-1.850	0.0213
CoSV%	0.268	2.825	6.122	1.880
MaH%	0.648	-3.422	-5.783	-4.420
MaV%	0.447	-0.312	-0.601	-2.491
MolH%	0.877	2.376	2.205	0.859
MolV%	0.247	-0.006	1.185	0.636
JH%	0.635	1.880	0.866	-0.772
JV%	0.547	0.247	1.063	-0.091
ZyH%	0.716	-1.395	-1.579	-2.526
ZyV%	0.411	1.362	3.071	-1.769
Ramus %	0.002*	-0.653	-2.452**	0.214

*p-values < 0.05

**Significantly different from the other two groups in the same row

Table 3.9. Multiple Linear Regression Analysis Results. Asymmetry Measurements Showing Significance in Explaining the Variability of the Dependent Variables TMJID R, TMJ ID L, R-L, and R+L. Females

Dependent variable	R^2	Independent variable	P value	Correl. coefficient
TMJID R	0.103	AgV%.abs	0.014	+0.276
		Ramus%.abs	0.036	+0.240
TMJID L	0.036	CoSH%.abs	0.038	-0.115
R-L	0.206	Ramus%	0.001	-0.407
		ANS-FM	0.022	-0.178
		InI	0.020	+0.152
R+L	0.046	ANS-FM.abs	0.031	-0.241

References

1. Lundstrom A. Some asymmetries of the dental arches, jaws and skull, and their etiological significance. Am J Orthod 1961;47:81-106
2. Cohen MM. Perspectives on craniofacial asymmetry. I. The biology of asymmetry. Int J Oral Maxillofac Surg 1995; 24:2-7.
3. Cook JT. Asymmetry of the Craniofacial Skeleton. Brit J Orthod 1980;7:33-8.
4. Zaidel DW, Chen AC, German C. She is not a beauty even when she smiles: Possible evolutionary basis for a relationship between facial attractiveness and hemispheric specialisation. Neuropsychologia 1995;33:649-55.
5. Peck S, Peck L, Kataja M. Skeletal Asymmetry in aesthetically pleasing faces. Angle Orthod 1990;61:43-8.
6. Vig PS, Hewitt AB. Asymmetry of the human facial skeleton. Angle Orthod 1978;48:141-8
7. Hewitt AB. A Radiographic study of Facial Asymmetry. British J Orthod 1974;2:37-40.
8. Letzer GM, Kronman JH. A posteroanterior Cephalometric Evaluation of Craniofacial Asymmetry. Angle Orthod 1967;37:205-11.
9. Chebib FS, Chamma AM. Indices of Craniofacial Asymmetry. Angle Orthod 1981;51:214-26.
10. Shah SM, Joshi MR. An assessment of Asymmetry in the Normal Craniofacial Complex. Angle Orthod 1978;48:141-8.
11. Farkas LG, Cheung G. Facial Asymmetry in Healthy North American Caucasians. An Anthropometrical Study. Angle Orthod 1981;51:70-7.
12. Ferrario VF, Sforza C, Poggio CE, Tartaglia G. Distance from Symmetry: A three-Dimensional Evaluation of Facial Asymmetry. J Oral Maxillofac Surg 1994;52:1126-32.
13. Melnik AK. A cephalometric study of mandibular asymmetry in a longitudinally

followed sample of growing children. Am J Orthod Dentofac Orthop 1992;101:355-66

14. Mulick JF. An investigation of craniofacial asymmetry using the serial twin-study method. Am J Orthod 1965;51:112-29.
15. Burke PH. Serial Observation of Asymmetry in the Growing Face. British J Orthod 1992;19:273-85.
16. Cohen MM. Perspectives on craniofacial asymmetry. II. Asymmetric Embryopathies. Int J Oral Maxillofac Surg 1995; 24:8-12.
17. Cohen MM. Perspectives on craniofacial asymmetry. III. Common and/or well known causes of asymmetry. Int J Oral Maxillofac Surg 1995;24:127-33.
18. Cohen MM. Perspectives on craniofacial asymmetry. IV. Hemi-asymmetries. Int J Oral Maxillofac Surg 1995;24:134-141.
19. Cohen MM. Perspectives on craniofacial asymmetry. V. The craniosynostoses. Int J Oral Maxillofac Surg 1995;24:191-194.
20. Cohen MM. Perspectives on craniofacial asymmetry. VI. The hamartoses. Int J Oral Maxillofac Surg 1995;24:195-200.
21. Bishara S, Burkey PS, Kharouf JG. Dental and facial asymmetries: a review. Angle Ortho 1994; 64:89-98.
22. Boering G. Arthrosis deformans van het kaakgewricht. Stafley en Tholen, Leiden, 1966
23. Ricketts RM. Clinical implications of the temporomandibular joint. Am J Ortho 1966 ;52 (6):416-39
24. Nickerson JW, Boering G. Natural Course of Osteoarthrosis as it relates to Internal derangement of the Temporomandibular Joint. Oral Maxillofac Clinics North Amer. 1989;1(1):27-45.
25. Mintz SS. Craniomandibular dysfunction in Children and Adolescents: A review. J of Craniomand Practice. 1993;Vol 11 (3): 224-231.
26. Schiffman EL, Anderson GC, Fricton JR, Lindgren BR. The Relationship Between

Level of Mandibular Pain and Dysfunction and Stage of Temporomandibular Joint Internal Derangement. J Dent Res 1992;71(11):1812-1815.

27. Tallents RH, Katzberg RW, Murphy BS, Proskin H. Magnetic Resonance imaging findings in asymptomatic volunteers and symptomatic patients with temporomandibular disorders. J Prosthet Dent 1996;75:529-33.
28. Katzberg RW, Westesson PL, Tallents RH, Drake CM. Anatomic Disorders of the Temporomandibular Joint Disc in Asymptomatic Subjects. J Oral Maxillofac Surg 1996;54:147-53.
29. Paesani D, Westesson PL, Hatala M, Tallents RH, Kurita K. Prevalence of Temporomandibular Joint derangement in patients with craniomandibular disorders. Am J Orthod Dentofac Orthop 1992;101:41-7.
30. Ishigaki S, Bessette RW, Maruyama T. The distribution of internal derangement in patients with temporomandibular joint dysfunction-prevalence, diagnosis and treatments. The J Craniomand Pract 1992;10:289-96.
31. Katzberg RW, Tallents RH, Hayakawa K, Miller TL, Goske MJ, Wood BP. Internal derangements of the temporomandibular joint: findings in the pediatric age group. Radiology 1985;154:125-7.
32. Lieberman JM, Hans MG, Rozencweig G, Goldberg HS, Bellon EM. MR Imaging of the Juvenile Temporomandibular Joint: Preliminary Report. Radiology 1992;182:531-4.
33. Hans MG, Lieberman J, Goldberg J, Rosencweig G et al. A comparison of clinical examination, history, and magnetic resonance imaging for identifying orthodontic patients with temporomandibular joint disorders. Am J Orthod Dentofac Orthop. 1992;101:54-9.
34. Dibbets, JMH. Juvenile TMJ Joint Dysfunction and Craniofacial Growth: A statistical Analysis. Stafley and Tholen, Leiden, 1977.
35. Dibbets, JMH. Van der Weele LT, Uildriks AKJ. Symptoms of TMJ dysfunction: Indicators of growth patterns? The J of Pedodontics,vol. 9:265-84; 1985

36. Westesson PL, Tallents RH, Katzberg RW, Guay G. Radiographic Assessment of Asymmetry of the Mandible . AJNR Am Neuroradiol 1994;15:991-9.

37. Shellhas KP, Piper MA, Omlie MR. Facial Skeleton Remodelling Due to Temporomandibular joint Degeneration: An Imaging Study of 100 Patients. AJNR 11:541-551. May/ June 1990; AJR 155: August 1990.

38. Shellhas KP, Piper MA, Bessette RW, Wylkes CH. Mandibular Retrusion, Temporomandibular Joint Derangement, and surgery planning. Plastic and Reconstr Surg 90(2):218-229; 1990.

39. Shellhas KP, Pollei SR, Wilkes CH. Pediatric internal derangements of the temporomandibular joint: Effect on facial development. Am J Orthod Dentofac Orthop 1992;101:79-83.

40. Dibbets JMH, Carlson DS. Implications of Temporomandibular Disorders for Facial Growth and Orthodontic Treatment. Semin Orthod 1995;1:258-272.

41. Major PW, Johnson DE, Hesse KL, Glover KE. Landmark identification error in posterior anterior cephalometrics. Angle Orthod 1994;64:447-54.

42. Nebbe B, Prasad, Hatcher D, Major PW. Quantitative assessment of the temporomandibular joint disc status. Oral Surg Oral Med Oral Path Oral Radiol Endod (accepted for publication August 1997)

43. MacLennan R. Interrater Reliability with SPSS for Windows 5.0. The American Statistician 1993;47:292-6.

44. Dahlberg G ed. Statistical Methods for medical and biological students. London: G Allen and Unwin Ltd, 1940

45. Fisher LD, Van Belle G. Biostatistics: a methodology for the health sciences. A Wiley Interscience Publication, John Wiley and Sons, Inc. New York 1993;531-4.

46. Westesson PL. Katzberg RW, Tallents RH. Et al. TMJ: comparison of MRI images with cryosection anatomy. Radiology. 1987;164:59-64.

47. Tasaki MM, Westesson PL, Isberg AM, Ren YF, Tallents RH. Classification and prevalence of temporomandibular joint disk displacement in patients and symptom-

free volunteers. Am J Orthod Dentofac Orthop 1996;109:249-62.

48. Westesson PL, Eriksson L, Kurita K. Reliability of a negative clinical temporomandibular joint examination: Prevalence of disk displacement in asymptomatic temporomandibular joints. Oral Surg Oral Med Oral Pathol. 1989;68:551-4.

49. Drace JE, Enzmann DR. Defining the Normal Temporomandibular Joint: Closed-, Partially Open- and Open-mouth MR Imaging of Asymptomatic Subjects. Radiology.1990;177:67-71.

50. Kjellberg H, Fasth A, Kiliaridis S, Wenneberg B et al. Craniofacial structure in children with juvenile chronic arthritis (JCA) compared with healthy children with ideal or postnormal occlusion. Am J Orthod Dentofac Orthop 1995;107:67-78.

51. Jamsa T, Ronning O. The facial skeleton in children affected by rheumatoid arthritis-a roentgen-cephalometric study. Europ J Orthod 1985;7:48-56.

52. Stabrun AE. Mandibular morphology and position in juvenile rheumatoid arthritis. A study on posterior-anterior radiographs. Europ J Orthod 1985;7:288-98.

53. Stabrun AE, Larheim HM, Hoyeraal HM, Rosler M. Reduced mandibular dimensions and asymmetry in juvenile rheumatoid arthritis. Arthritis and Rheum 1988;31:602-11.

54. Larheim TA, Haanes HR, Dale K: Radiographic temporomandibular joint abnormality in adults with micrognathia and juvenile rheumatiod arthritis. Acta Radiol Diagnos1981;22:495-504.

55. Stringert HG, Worms FW. Variations in skeletal and dental patterns in patients with structural and functional alterations of the temporomandibular joint: A preliminary report. Am J Ortho 89:285-297,1986.

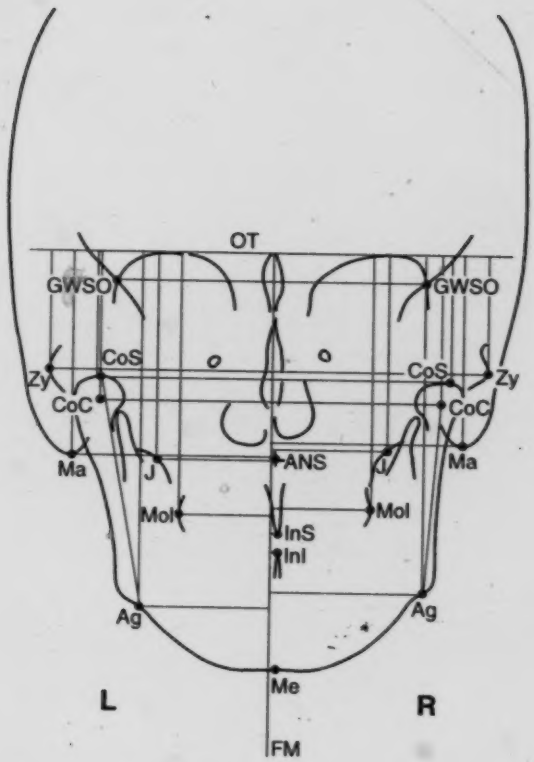

FIGURE 3.1 Cephalometric Landmarks, Reference Planes and Asymmetry Measurements

FIGURE 3.2 Establishment of Plane for Quantitive MRI Assessment

FH- Frankfort Horizontal

ERP- Eminence Reference Plane

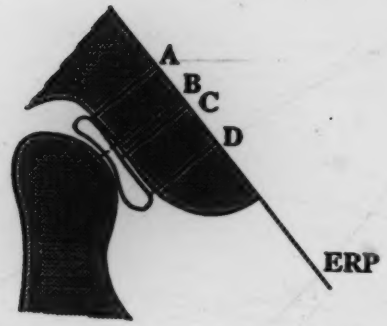

FIGURE 3.3 Reference Points for Determining Disc Lenght and Disc Displacement

A-posterior band ; B-condylar load point

C-midpoint of the disc ; D-anterior band

CHAPTER IV

DISCUSSION AND RECOMMENDATIONS

4.1 GENERAL DISCUSSION

The goal of this investigation was to explore the relationship between TMJ Internal Derangement and craniofacial morphology and asymmetry in adolescent patients. The sample group consisted of adolescent patients seeking orthodontic treatment. Therefore, the findings are limited to a portion of the population. However, the prevalence of moderate malocclusion in the general population ranges from 50 to 75 %. [1] The results of this study may be applicable to large segment of the adolescent population.

Complex hormonal changes initiate the adolescent growth spurt. The similarity of craniofacial growth with somatic growth suggests that identical intrinsic factors influence the circumpubertal craniofacial growth spurt. [1-3] Extrinsic factors intertwine with the intrinsic growth potential and play an important role in modifying the final shape and size of the craniofacial skeleton. [2,4] Bjork's study on artificially deformed ancient Peruvian skulls illustrated the pliability of the craniofacial skeleton in response to mechanical pressure and the compensatory growth of facial bones in response to altered cranial base. [5] Mechanical stimuli from the functional environment will determine the ultimate shape of the mandibular condyle. [6] The purpose of this investigation was to evaluate whether a TMJ ID is a factor that can exert substantial influence on the transverse and vertical growth of the mandibular condyle and ramus. Except for female patients with bilateral TMJ ID, there were no clinically significant parameters that would distinguish adolescents with TMJ ID from the control group. The findings revealed that in females with bilateral TMJ ID there is significant asymmetry between the right and left vertical antegonion, which is due to shorter ramus on the right side. The outcome for boys and girls could have been influenced by the difference in timing of adolescent growth spurt. The average age in both gender groups in this study was very similar. Notwithstanding individual variation, girls were possibly at the peak or towards the end of their growth spurt while most of the boys in our sample were

likely at the beginning of their growth acceleration. Another significant factor is the sexual dimorphism in prevalence of TMJ ID. The male group did not provide sufficient number of patients with TMJ ID, which hampered the analysis and produced inconclusive findings.

The timing of growth direction is important factor to consider in the search for growth patterns and altered morphology. The sequence in which craniofacial growth is completed in the three planes of space is such that growth in width is completed first, then growth in length, and finally growth in height. Growth rate in width of both jaws, including the width of the dental arches, tends to decrease before the adolescent growth spurt and is affected minimally by adolescent changes. [1,2] On the contrary, vertical growth continues during adolescence at greater rate in both sexes than growth in length and width. For this reason, changes in the transverse plane due to a factor that may alter growth in the adolescent years would not be as pronounced as vertical changes. The results of this investigation confirmed this expectation; transverse measurements were similar between patients and controls, while several vertical measurements were found statistically significantly different.

It appears that bilateral TMJ ID is more likely to contribute to altered mandibular vertical growth in comparison with unilateral TMJ ID. The literature on children and adolescents with juvenile rheumatoid arthritis has demonstrated reduced vertical height in the ramus region and reduced total facial height due to failure of vertical growth. [7] Greater variance of ramus height asymmetry and overall mandibular length asymmetry was found as compared with healthy children. Transverse mandibular dimensions were similar to controls. In adult patients with JRA mandibular asymmetry is infrequent. [8] These studies imply that the time period between 7 and 17 years of age may be a transitional stage from unilateral to bilateral growth retardation. A similar concept could apply to internal derangement of the TMJ-s. The available literature suggests that

asymmetry of unknown origin tends to improve with growth. [9-11] A longitudinal investigation is required to comprehend the craniofacial development of patients with unilateral or bilateral TMJ ID. Female patients with bilateral TMJ ID may continue to show morphologic changes of the ramus on the left side that could result in decrease of mandibular asymmetry and levelling of the right and left antegonion. These patients should then exhibit a smaller vertical mandibular size in comparison with controls. Longitudinal studies have shown that TMJ dysfunction can be self limiting and fluctuating over time. [12] Gradual increase of subjective symptoms and clinical signs with age has been reported. These findings are most often mild and do not require treatment. [13,14] Due to the cross sectional nature of this investigation we can not infer what the future growth of adolescents with TMJ ID will be, i.e., whether development will continue at a normal rate. A longitudinal investigation could clarify these questions.

The only equivalent investigation previously reported is the work of Dibbets in 1977. [15] Although progressive asymmetry was observed in individual children, asymmetry was not statistically proven in a sample of 112 children with Class II, division 1 malocclusion. Criteria for TMJ dysfunction in this study included presence of subjective and objective signs and symptoms as well as evidence of ADJ determined on a transcranial radiographic view. The unequivocal lack of significant difference in this particular investigation could be due to the difference in TMJ dysfunction criteria, sample characteristics and PA analysis.

Mandibular asymmetry can be displacement asymmetry due to functional shift into centric occlusion or skeletal asymmetry due to true anatomical jaw size discrepancy. [16] In young patients, lateral mandibular functional shift due to dental cross bites may induce remodelling changes within the TMJ-s and lead to structural mandibular asymmetry.[17] Therefore, in orthodontic treatment planning the presence of transversal

occlusal discrepancies requires early treatment. Occlusal problems, such as Class III malocclusion, nonworking side interferences, posterior cross bites, anterior open bites were not studied in the present investigation. The relative contribution of occlusal factors to craniomandibular disorders is not clearly identified. [13, 17, 18] However, evaluation of functional malocclusion as well as morphologic malocclusion should be included in future studies of craniofacial development and TMJ ID. [19] Occlusal characteristics may modify the effect of TMJ ID on the development of various craniofacial patterns.

The PA analysis that was employed in this work might have measured only displacement mandibular asymmetry. However, if a mandibular functional shift existed this should have resulted in discernible transverse asymmetry of the mandible relative to the facial axis. The results did not reveal such asymmetries. The one parameter unaffected by mandibular shift is ramus height, which is a measure between two anatomic points of the mandible. In the female group, the percentage of ramus height difference was significant for patients with unilateral TMJ ID, although minimal and of no clinical importance.

Other etiologic factors that may create mandibular asymmetry are conditions such as hemimandibular hypo- or hypertrophy, which are relatively uncommon, or isolated condylar hypo- or hyperplasia. [20] Tallents et al. suggested that unilateral condylar hyperplasia and unilateral internal derangement may have similar clinical features. [21] Therefore, whether the cause of mandibular asymmetry is deficient or excessive growth should be determined.

This investigation focused on TMJ soft tissue abnormality as opposed to osseous changes. Previous literature suggested that only patients with osseous TMJ deformity have distinct craniofacial morphology from patients with subjective or objective signs

of TMD. [15] There are two concepts in the literature regarding the interrelation between TMJ ID and osteoarthrosis. [22] According to the first, TMJ ID precedes osseous changes; depending on the duration and severity of the structural disorder, osseous break down may follow. Stegenga et al. proposed a contradictory model. [23] They believe that in many cases of craniomandibular pain and dysfunction the initiating cause is osteoarthrosis. Since in the initial stages OA involves ultrastructural tissue break down which involves the articular cartilage of the condyle, radiographs can not verify these changes. They consider TMJ ID to be a sign that accompanies OA rather than its cause. Pullinger [24] and Seligman [25] postulated that TMJ ID in patients under 35 years of age precedes DJD, while in older patients it is secondary to DJD. Histologic changes of TMJ ID include fibrosis and change in vascularity of the retrodiscal pad, altered shape and internal structure of the disc, elongation of the capsule that attaches the disc to the condyle. [26,27] Condylar surface erosions can be found in young adult TMJ-s, but articular soft tissue fills the osseous concavities and provides smooth articular surface. [28] Regardless of whether the TMJ ID precedes or results from DJD, it is a factor that alters intracapsular relationships and TMJ biomechanics and may exert influence on subsequent mandibular growth. It should be established whether patients who show both soft tissue changes and radiographic changes of the TMJ have characteristic craniofacial morphology and associated asymmetry.

The method that was used in this study to assess craniofacial morphology is not without limitations. The sagittal dimension, which is absent on a PA cephalogram, may influence the projected image of mandibular size and shape on the radiograph. The farther the object is from the film, the greater is the enlargement. Patients may have asymmetric bicondylar position. The left condyle can be positioned more anteriorly and medially in comparison to the right condyle. [29] The anteroposterior location of the glenoid fossae can also affect the position of the TMJ relative to the film. With normal growth the glenoid fossae remodel and drift either posteriorly or anteriorly. [30,31]

Patients with TMJ dysfunction have hyperdivergent skeletal pattern due to vertical growth direction and posteriorly inclined condyle. [15, 32] Also in patients with vertical growth pattern the posterior displacement of the glenoid fossa can be more pronounced. [31] The inclination of the rami in relation to the film plane could also introduce error. For instance, a ramus that leans posteriorly and is at an angle to the film will be foreshortened compared to ramus that is more upright and more perpendicular to the film. At least two radiographic views that are orthogonal to each other can describe craniofacial asymmetry. [33,34] Baumrind discussed the conceptual basis for three-dimensional cephalogram. [35] CT scans can be used for a three-dimensional analysis of the craniofacial structures but greater radiation and increased cost is involved. [36] Photographs can be used to evaluate craniofacial morphology in three-dimensions.[37,38] Although it is generally accepted that soft tissues tend to camouflage underlying osseous asymmetry, [37,39] it would be valuable to apply these techniques to determine the facial appearance of patients with TMJ ID. Functional muscle disbalance and associated masticatory muscles hypo- or hypertrophy that TMJ ID patients have could create a clinical impression of facial asymmetry.

There are no studies in the literature that have evaluated the validity of the PA Cephalogram. Validity is the extent to which, in absence of measurement error, the value obtained represents the object of interest. [40] It remains to be determined whether landmarks marked on a PA cephalogram truly correspond to the anatomical structures in question. Potential sources of error in PA cephalometric analysis are anatomical intraindividual variations of the reference points (external auditory meati), improper patient positioning in the cephalostat, landmark identification error, observer bias (systematic error). The ear rod axis may not always be perpendicular to the film. Farkas [9] measured the variation of the vertex-tragion distance in 153 healthy children and found it asymmetric in 48 (31.4%). He did not report the direction or the extent of this asymmetry. If a patient has visibly asymmetrical external auditory canals only one ear

rod of the cephalostat can be inserted and the midsagittal plane can be lined up perpendicular to the radiographic cassette. [41] Patient positioning in the cephalostat when PA images were taken for this study was with Frankfort horizontal to the floor. This could have introduced error; however, none of the patients exhibited unusually large asymmetry or distorted craniofacial morphology. It can be concluded that patient position in the cephalostat was adequate. Asymmetry measures are most susceptible to error due to rotations around the vertical axis, while rotations around transversal and sagittal axis will not alter right-left side size ratio. Major et al. evaluated the effect of head rotation on cephalometric analysis. Five degrees of rotation around a vertical or transversal axis did not affect cephalometric distances. [42] It can be assumed that the effect of head rotation on results was minimal if proper head position was insured in the cephalostat.

Another problem with PA analysis is that there are no standards for normal craniofacial asymmetry. Bolton analysis averaged right and left side measurements to compensate for asymmetry. [43] The Comprehensive Ricketts Analysis included some evaluation of asymmetry, such as lower dental midline deviation and tilt of occlusal plane measured at the level of first maxillary molars. [44] Clinical deviation for these measurements can be 1.5 mm and 0-2 mm respectively. In an anthropometrical study soft tissue asymmetry in normal children ranged from 2.5 to 3.6 mm in boys and from 2.4 to 3.8 mm in girls. [9] None of these reported values can be directly applied to the presented sample without introducing significant bias.

One observer was involved in PA tracing and cephalometric analysis. Reproducibility of measurements in this study was smaller [45] or comparable to previously published studies. [46] Intraobserver reliability is smaller than interobserver variability. [46] Systematic errors due to differences between observers involved was minimised. Landmarks' identification is the largest source of random errors. Condylar landmarks

and ramus height had larger measurement error. Osseous tissues' superimposition obscured the image of the condyle and affected the validity of these measurements. Oblique PA cephalogram can improve the image of the condyle.[7,47]

4.2 RECOMMENDATIONS FOR FUTURE STUDIES

Important mandibular vertical parameters emerged in the statistical analyses in this study. The findings suggest that TMJ ID may be a factor that influences mandibular growth. We need to investigate in the future whether TMJ ID can alter vertical growth to a clinically disconcerting degree. The following recommendations should guide future research in this area:

1. The lack of adequate patient numbers in the male sample necessitates larger sample size. Also, the female group should include more adolescents with TMJ ID which will result in more conclusive findings with respect to unilateral and bilateral TMJ involvement.

2. Morphologic occlusal evaluation of patients should be included as a variable since certain dental malocclusions may affect the centric occlusion position of the mandible. Patients should be screened for different facial types in the transversal dimension (dolichocephalic, mesocephalic and brachycephalic) and vertical or horizontal growth direction (short or long face). Once again, larger sample will facilitate such distinction between groups.

3. Supplementary radiographs such as orthopantomograph may be used to measure mandibular size. Condylar hyperplasia should be eliminated as a factor that may affect mandibular size and contribute to mandibular asymmetry. In addition, the sagittal dimension should be evaluated using combined radiographs including lateral and submental vertex cephalograms.

4. Validity of cephalometric landmarks on PA cephalogram should be tested. For this purpose, dry skulls with markers placed on the anatomical areas of interest can be used.

The sensitivity of the PA cephalogram in discerning artificially created asymmetry should also be established.

5. Individual variations of external auditory meati of each patient should be measured in reference to a stable external point.

6. Digitization instead of manual landmark registration will require less time to complete cephalometric analysis and obtain measurements, without compromising accuracy. Method error of the digitizing unit should complement the preliminary evaluation of error in methodology.

7. A computer program may be used to measure both displacement and structural mandibular asymmetry . This will allow to distinguish true skeletal mandibular problems.

8. Soft tissue evaluation from facial photographs may be included and compared to underlying osseous morphology. The photographs should be taken in a standardized manner.

9. Clinical signs and symptoms should be combined to evaluate whether compromised function is a significant covariate in explaining growth alterations.

10. TMJ Internal Derangement should be compared with osseous condylar changes. Condylar morphology should be described in terms of deformities, intraindividual size difference, osseous defects etc.

11. Longitudinal follow up of patients will aid to elucidate the time factor and its effect on morphologic change.

References

1. Proffit WR, Fields HW. Contemporary Orthodontics. St Louis:Mosby, 1993:87-102.
2. Ranley DM. A Synopsis of Craniofacial Growth. Connecticut: Appleton & Lange, 1988.
3. Luder HU. Evidence of a Pubertal Growth Spurt in Mandibular Condylar Growth of Nonhuman Primates. In: Carlson DS, Ribbens KA. Craniofacial Growth During Adolescence, Monograph 20, Craniofacial Growth Series. Center fro Human Growth and Development, University of Michigan Ann Arbor:1987;49-68.
4. Mc Namara JA. Functional determinants of craniofacial size and shape. Eur J Orthod1980;2:131-159)
5. Bjork A, Bjork L. Artificial Deformation and Craniofacial Asymmetry in Ancient Peruvians. J Dent Res 1963;43:353-62.
6. Copray JC, Jansen HW, Duterloo HS. The role of biomechanical factors in mandibular condylar cartilage growth and remodelling in vitro. In: Carlsson DS, McNamara JA, Ribbens KA. Developmental Aspects of Temporomandibular Joint Disorders. Monograph 16, Craniofacial Growth Series. Center for Human Growth and Development, University of Michigan, Ann Arbor:1985;235-69.
7. Stabrun AE. Mandibular morphology and position in juvenile rheumatoid arthritis. A study on postero-anterior radiographs. Eur J Orthod 1985;7:288-98.
8. Larheim TA, HaanaesHR, Dahle K. Radiographic temporomandibular joint abnormality in adults with micrognathia and juvenile rheumatoid arthritis. Acta Radiologica Diagnosis 1981;22:495-504.
9. Farkas LG, Cheung G. Facial Asymmetry in Healthy North American Caucasians. An Anthropometrical Study. Angle Orthod 1981;51:70-7.
10. Melnik AK. A cephalometric study of mandibular asymmetry in a longitudinally followed sample of growing children. Am J Orthod Dentofac Orthop 1992;101:355-66

11. Burke PH. Serial Observation of Asymmetry in the Growing Face. British J Orthod 1992;19:273-85.

12. Okeson JP ed. Orofacial Pain: Guidelines for Assessment, Diagnosis and Management. The American Academy of Orofacial Pain. Quintessence Publishing Co, Inc. Carol Stream ,Illinois 1996.

13. Egermark I, Thilander B. Craniomandibular disorders with special reference to orthodontic treatment: An evaluation from childhood to adulthood. Am J Orthod Dentofac Orthop 1992;101:28-34.

14. Wanman A, Agerberg G. Two-year longitudinal study of symptoms of mandibular dysfunction in adolescents. Acta Odontol Scand. 1986;44:321-31.

15. Dibbets, JMH. Juvenile TMJ Joint Dysfunction and Craniofacial Growth: A statistical Analysis. Stafley and Tholen, Leiden, 1977.

16. Schmid W, Mongini MD, Felisio A. A computer based assessment of structural and displacement asymmetries of the mandible. Am J Orthod Dentofac Orthop 1991;100:19-34.

17. Heikinheimo K, Salmi K, Myllarniemi S, Kirveskari. A longitudinal study of occlusal interferences and signs of craniomandibular disorder at the ages of 12 and 15 years. Europ J Orthod 1990;12:190-7.

18. Riolo ML, Brandt D, TenHave TR. Associations between occlusal characteristics and signs and symptoms of TMJ dysfunctions in children and young adults. Am J Orthod Dentofac Orthop 1987;92:467-77.

19. Thilander B. Temporomandibular Joint Problems in Children.
In: Carlsson DS, McNamara JA, Ribbens KA. Developmental Aspects of Temporomandibular Joint Disorders. Monograph 16, Craniofacial Growth Series. Center for Human Growth and Development, University of Michigan, Ann Arbor:1985;89-104.

20. Cohen MM. Perspectives on craniofacial asymmetry. IV. Hemi-asymmetries. Int J Oral Maxillofac Surg 1995;24:134-141.

21. Tallents RH, Guay JA, RW Katzberg, W. Murphy. Angular and linear comparisons with unilateral mandibular asymmetry. J Craniomand Disord Facial Oral Pain 1991;5:135-42.

22. Kamelchuk LS, Major PW. Degenerative Disease of the Temporomandibular Joint. J Orofac Pain 1995; 9:168-80.

23. Stegenga B, de Bont LGM, Boering G. Osteoarthrosis as the Cause of Craniomandibular Pain and Dysfunction: A Unifying Concept. J Oral Maxillofac Surg 1989;47:249-256.

24. Pullinger AG, Seligman DA. TMJ Osteoarthrosis: A differentiation of diagnostic Subgroups by symptom history and demographics. J Craniomand Disord Facial Oral Pain 1987;1:251-6.

25. Seligman DA, Pullinger AG. TMJ derangements and osteoarthrosis subgroups differentiated according to active range of mandibular opening. J Craniomand Disord Facial Oral Pain 1988;2:35-40.

26. Scapino RP. Histopathology associated with malposition of the human temporomandibular joint disc. Oral Surg 1983;55:382-97.

27. Heffez LB, Jordan SL. Superficial vascularity of temporomandibular joint retrodiskal tissue: an element of the internal derangement process. The J Craniomand Pract 1992;10:180-91.

28. Baldioceda F, Bibb CA, Pullinger AG. Distribution and histologic character of osseous concavities in mandibular condyles of young adults. J Craniomand Disord Facial Oral Pain 1990;4:147-53.

29. Pirttiniemi P, Raustia A, Kantomaa T, Pyhtinen J. Relationships of bicondylar position to occlusal asymmetry. Europ J Orthod 1991;13:441-5.

30. Droel R, Isaacson RJ. Some relationships between the glenoid fossa position and various skeletal discrepancies. Am J Orthod 1972;61:64-78.

31. Agronin KJ, Kokich VG. Displacement of the glenoid fossa: a cephalometric evaluation of growth during treatment. Am J Orthod 1987;91:42-8.

32. Stringert HG, Worms FW. Variations in skeletal and dental patterns in patients with structural and functional alterations of the temporomandibular joint: A preliminary report. Am J Ortho 89:285-297,1986.

33. Grayson B, Cutting C, Bookstein F, Kim H. The three dimensional cephalogram: Theory, technique, and clinical application. Am J Orthod Dentofac Orthop 1988;94:327-37.

34. Kaban LB, Mulliken JB, Murray JE. Three-dimensional approach to analysis and treatment of hemifacial microsomia. Cleft Palate J, 1981;18:90-9.

35. Baumrind S, Moffitt FH, Curry S. Three-dimensional x-ray stereometry from paired coplanar images: A progress report. Am J Orthod 1983;84:292-312.

36. Moss JP, Linney AD, Grindrod SR, Arridge SR. Three-dimensional visualisation of the face and skull using computerized tomography and laser scanning techniques. Eur J Orthod 1987;9:247-53.

37. Ferrario VF, Sforza C, Miani A, Tartaglia G. Craniofacial morphometry by photographic evaluations. Am J Orthod Dentofac Orthop 1993;103:327-37.

38. Ras F, Habets LL, Van Ginkel FC, Prahl-Andersen B. Method for quantifying facial asymmetry in three dimensions using stereophotogrammetry. Angle Orthod 1995;65:233-9.

39. Peck S, Peck L, Kataja M. Skeletal Asymmetry in aesthetically pleasing faces. Angle Orthod 1990;61:43-8.

40. Houston WJB. The analysis of errors in orthodontic measurements. Am J Orthod 1983;83:382-90.

41. Grummons DC, Kappeyne, van de Coppelo MA. A Frontal Asymmetry Analysis. JCO 1987;21:448-65.

42. Major PW, Johnson DE, Hesse KL, Glover KE. Effect of head orientation on posterior anterior cephalometric landmark identification. Angle Orthod 1994;66:51-60.

43. Broadbent HB Sr, Broadbent HB Jr, Golden WH. Bolton Standards of Dentofacial

Developmental Growth. The C .V. Mosby Company, Saint Louis, 1975.

44. Ricketts RM, Roth RH, Chaconas SJ. Orthodontic Diagnosis and Planning...their roles in preventive and rehabilitative dentistry. Rocky Mountain Data Systems. Rocky Mountain /Orthodontics, 1982: pp 137-42.
45. El Mangoury NH, Shaheen SI, Mostafa YA. Landmark identification in computerized posteroanterior cephalometrics. Am J Ortho Dentofac Orthop 1987;91:57-61.
46. Major PW, Johnson DE, Hesse KL, Glover KE. Landmark identification error in posterior anterior cephalometrics. Angle Orthod 1994;64:447-54.
47. Lund K. Mandibular growth and remodelling processes after condylar fracture. A longitudinal roentgencephalometric study. Academic disertation. Acta Odont Scand 1974;32:sup. 64.